UTD Inc.

Feasibility Study of the Geotextile Waste Filtration Unit

February 10, 2000

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave Blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	10 February 2000	Final Report 10 August 1999 to 10 February 2000

4. TITLE AND SUBTITLE

Feasibility Study of the Geotextile Waste Filtration Unit

5. FUNDING NUMBERS

Army Corps of Engineers Contract Number DACA39-99-C-0036

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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

US Army Corps of Engineers Cold Regions Research
Engineering Laboratory
72 Lyme Road, Hanover, New Hampshire 03755-1290

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES The District of Columbia's Advanced Wastewater Treatment Plant at Blue Plains provided the site for collecting wastewater used in the research and graciously provided the analytical testing of samples.

12a. DISTRIBUTION/AVAILABILITY STATEMENT (see Section 5.3b of this solicitation)

Approved for Public Release; Distribution Unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

Report developed under STTR contract for the Feasibility Study of the Geotextile Waste Filtration Unit. This study determined the feasibility of developing a deployable geotextile-based wastewater filtration unit. Specifically, it is feasible to develop a filtration unit capable of achieving treatment results equivalent to primary settling tanks in a conventional wastewater treatment plant. The best approach to treating the liquid waste streams in Force Provider modules is to combine the blackwater and graywater wastes and then treat the mixture. Geotextile-based filtration units can be used for conventional primary treatment. A suitable secondary treatment subsystem needs to be developed for secondary TSS and BOD removal. Secondary clarification can be achieved using geotextile-based filtration units. The spent geotextile fabric with entrained waste can be destroyed in an incinerator subsystem.

14. SUBJECT TERMS Geotextile filter, STTR Report, Total Suspended Solids (TSS) and Biochemical Oxygen Demand (BOD) removal from wastewater, secondary wastewater treatment.

15. NUMBER OF PAGES 88

16. PRICE CODE

17. SECURITY CLASSIFICTION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR

Standard form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

PREFACE

This report summarizes the activities and results of a study performed for the Department of the Army, Corps of Engineers, Cold Regions Research and Engineering Laboratory under contract number DACA39-99-C-0036. The work was performed by a team of engineers from UTD Inc. and the Catholic University of America under the Department of Defense Small Business Technology Transfer (STTR) program.

We would like to express our appreciation for the assistance provided by the District of Columbia Water and Sewer Authority. Messrs. Mike Marcotte, Akile Tesfaye, and Jerry Dakita were extremely helpful in enabling us to runs tests and analyze the results at the Blue Plains wastewater treatment plant.

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EXECUTIVE SUMMARY

The objective of this study was to determine the feasibility of developing a deployable geotextile-based wastewater filtration unit. More specifically, the intent was to find out if it is feasible to develop a filtration unit capable of achieving treatment results equivalent to primary settling tanks in a conventional wastewater plant.

This research was motivated by the need for military units to pay for liquid waste removal and disposal when they are deployed in the field for varying lengths of time. Traditional wastewater treatment systems require a significant investment in real estate and equipment, neither of which are mobile or reusable. The alternative that is frequently used today is to pay the expense of hiring a local entity to haul and dispose of the liquid waste. The concept of using a filtration unit instead of settling tanks was developed to avoid the risk and expense of local hauling and dumping and to provide an indigenous mobile treatment capability. The system identified offers a potential savings of $2,584 per day. Further, the filtration process enables the management of ash instead of sludge, thus reducing the hazards that accompany the handling of sludge materials. All equipment items and supplies accommodate as few as four (4) standard ISO containers. This concept is depicted in the process flow diagram in Figure 1-1.

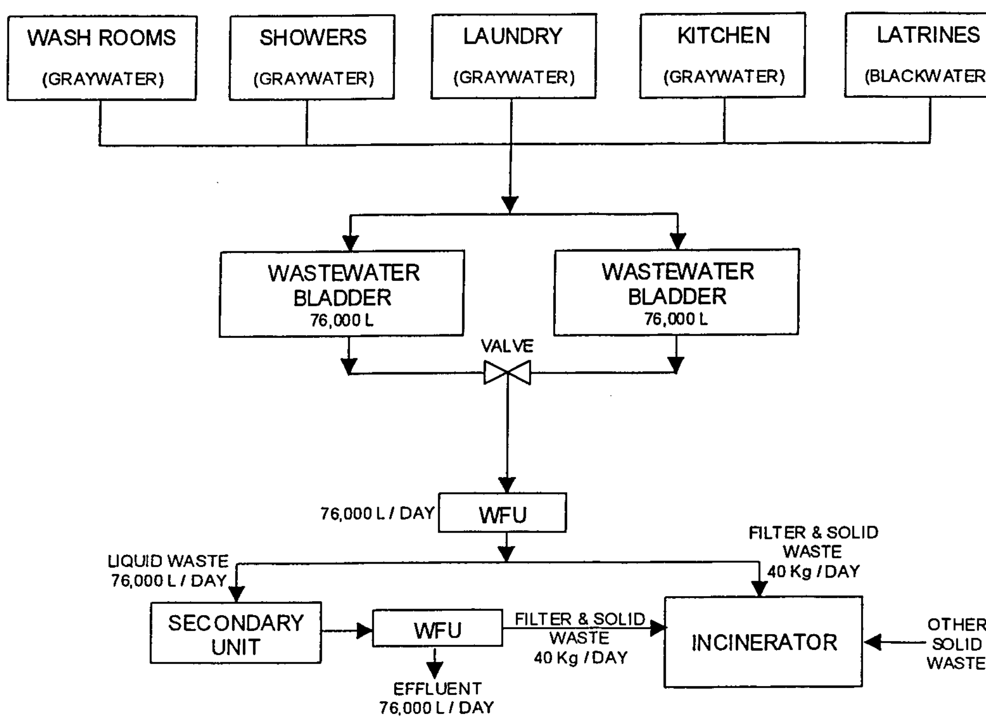

Figure 1-1. WFU Process Flow and Mass Balance Diagram

1.1 Major Findings:

- It is feasible to develop a deployable, geotextile-based, wastewater treatment unit.
- Filtration units with geotextile filter media can produce Total Suspended Solids (TSS) and Biochemical Oxygen Demand (BOD) reductions of approximately 70% and 50%, respectively, in a combined blackwater and graywater waste stream.
- The Wastewater Filtration Unit (WFU) is estimated to be capable of treating around 2,000 liters of wastewater per square meter of geotextile fabric during a ten minute exposure period.
- There is a strong indication that the presence or absence of particles in a narrow size range (close to 100 microns) is a primary driver of filter performance. Therefore, a simple evaluation of TSS levels is not sufficient to fully quantify filter behavior.
- Treatment costs for a system employing WFUs combined with appropriate secondary treatment methods and incinerators are estimated to be on the order of $.006 per liter ($.02 per gallon) of liquid waste treated. The Army currently pays between $.04 per liter ($.15 per gallon) to $.07 per liter ($.25 per gallon) to pump and haul liquid waste away.[1] Costs for existing off-the-shelf packaged treatment systems are in the $.26 per liter ($1 per gallon) to $.53 per liter ($2 per gallon) range while the cost for conventional in-ground systems is $1.05 per liter ($4 per gallon) to $5.81 per liter ($22 per gallon) range.[2]
- The WFU technology is scalable and can be applied to small (2,650 liters per day) as well as large (100,000 liters per day) liquid waste streams.
- Increasing the head level on the upstream side of the geotextile filter is estimated to have minimal impact on filter performance.
- Increasing the filter thickness appears to have minimal impact on filter performance.
- The WFU will be equally effective in treating a mixed stream of wastewater or separate streams of blackwater and graywater.
- Since the ultimate goal is to treat all liquid wastes to acceptable local discharge standards, a secondary treatment subsystem will need to be developed to treat the effluent from the WFU. A WFU, very similar to the one being developed for the primary treatment, will be capable of treating the discharge of the secondary subsystem to remove particulate matter in the secondary effluent.

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1 Army presentation at the WFU project kick off meeting hosted by CRREL at Hanover NH on September 8, 1999.

2 Smith-Vargo, L., *Packaged Systems for Small Wastewater Facilities*. Journal of Water Engineering & Management, Vol. 136, No. 9 (1989), 36-37.

- The optimum configuration for a Force Provider unit would be to treat a combined blackwater and graywater liquid waste stream. The existing graywater collection bladders would be suitable storage for a combined waste stream. The combined liquid wastestream would have a TSS of about 450 mg/l and a BOD of 620 mg/l based on the flow proportions.

- It is impractical to use stand-alone complete treatment units (primary filter unit, secondary treatment unit, incinerator, and secondary filter unit) for small liquid waste generators like individual latrines. While small WFUs are practical, secondary and incinerator subsystems are more cost effective when they are used for larger waste streams.

- A complete treatment system for a Force Provider module (as depicted in Figure 1-1) would consist of the combined liquid waste storage bladders, attached WFUs for primary treatment, a secondary treatment subsystem, WFUs for secondary effluent filtering, and an incinerator to dispose of the WFU filters and entrained waste.

- While an incinerator can be found to dispose of the minimal waste from one or more WFU(s), it is estimated to be more economical to install a larger incinerator and use it to burn a combination of solids from liquid waste treatment as well as other solid waste generated in the Force Provider.

- More research needs to be conducted to determine the performance of a moving filter, the effectiveness of different filter media, the combustion products of geotextiles and other filter media, the most appropriate secondary treatment system, and the impact of using the incinerator for both solid and liquid waste.

- Future testing will be of greatest value if it is performed at an operational Force Provider unit.

SECTION 2

DEFINITION OF SYSTEM REQUIREMENTS

The first task in the project was to determine what performance characteristics and physical limitations the WFU had to meet, and to define the solution space within which the WFU was required to operate by researching and defining the interface requirements, weight and size limitations, operating climates, and existing methods of collecting and storing liquid wastes.

2.1 FORCE PROVIDER CONSTRAINTS.[3]

The Force Provider module is a deployable habitat intended to accommodate 550 people with messing, berthing, and laundry facilities, as well as morale and recreation, retail, medical, and religious amenities. The need for a Force Provider capability resulted from support deficiencies identified during operation Desert Storm. Force Provider is a collective support package similar to the US Air Force "Harvest" family of systems. It is intended to provide front line soldiers with a break from combat operations and to support theater reception, reconstitution, humanitarian aid, and disaster relief missions. It is envisioned that as many as six Force Provider modules can be linked together to support as many as 3,300 personnel. Each Force Provider module is designed to be operated by 50 support personnel, making 600 as the total number of supported personnel in each Force Provider module.

The Force Provider module is air-transportable, containerized, and modular in order to enhance its deployability, transportability, and flexibility. The components of each module must fit into standard ISO containers that are 8 x 8 x 20 feet (2.4 x 2.4 x 6.1 meters) in size. The loaded weight of each ISO container is limited to 10,000 pounds (4,540 kg) because that is the handling capacity of the forklift that is provided with the module. The empty weight of the ISO container is 4,500 pounds (2,043 kg), so the equipment contained inside can weigh no more than 5,500 pounds (2,497 kg). However, it should be possible to use more than one ISO container to transport and store the components of the wastewater treatment system.

There are four latrines in each Force Provider module and each latrine has six commodes, one 6-foot trough urinal, two sinks, and an integral 350 gallon (1,325 liter) collection tank. Fresh water is used for flushing. The trough urinal empties into a small sump that discharges into the collection tank when full. Each of the commodes uses one-half gallon (1.9 liters) of water with each flush and empties waste into integral collection tank that forms the base of the latrine.

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3 Information in this section was collected from four sources:

Cost and Operational Effectiveness Analysis (COEA) for Graywater Treatment to Support Force Provider and DEPMEDS, March 26, 1997, prepared for the US Army Tank Automotive Command Mobility Technology Center – Belvoir under contract DAAK70-92-D-0003, DO 0055.

Operational Requirements Document (ORD) for Force Provider, June 23, 1993.

Telephone conversation with Mr. Mike Gallagher, Force Provider Program Manager's Office, of September 28, 1999.

TM 10-5419-2000-14, *Operator's, Unit, Direct Support and General Support Maintenance Manual for Force Provider Modules 1 through 4*, October 30, 1998.

The kitchen, showers, laundry, and wash basins empty into sumps which pump the graywater to a graywater collection main that feeds the waste by gravity to one of two 20,000 gallon (76,000 liter) bladders that retain the waste until it is removed for disposal. There is a grease trap in the line from the kitchen.

Each Force Provider module comes with a Wastewater Vacuum Trailer that is designed to vacuum out the integral 350 gallon (1,325 liter) latrine tank. The vacuum trailer has a 1,000 gallon (3,785 liter) capacity. The design concept required the vacuum truck to empty out the contents of each of the four latrines about twice a day. A fresh water hose is provided in each latrine to wash down the interior of the latrine tank while it is being emptied. There are two diesel-driven pumps, each rated at 125 gpm (473 lpm), that are provided with each module to be used for graywater transfer. Graywater is designed to be removed by vacuum trailer or pumped to a local municipal sewer system. A thirty day supply of spare parts is packed with each module. After those parts are exhausted, the normal logistics support train provides spares.

Placement of the components in a Force Provider module must be considered carefully to ensure the liquids flow as intended and that the pumps have sufficient head to overcome any elevation differences. Therefore, the layout of components in the module can vary depending on the terrain where the module is set up.

Electrical power for Force Provider comes from 27 generators, each with a 60 kW capacity. The generators are grouped in nine clusters of three generators each. The operating doctrine is to have two generators on-line at any time with the third off-line for refueling or maintenance. The preferred fuel for the generators and other fuel users in the module is JP-8 and the organic fuel storage capacity is 40,000 gallons (151,400 liters). Force Provider electrical equipment is required to operate at either 50 or 60 Hz.

The wastewater treatment system must be capable of operating in the 32 to 120 degrees Fahrenheit (0 to 49 degrees Centigrade) temperature range while the desired operational capability for temperature is -15 to 120 degrees Fahrenheit (-26 to 49 degrees Centigrade). The Force Provider system includes an add-on cold weather kit that can be used to heat components and prevent them from freezing. It consists largely of electric-resistance strip heaters for piping and heated enclosures for bladders.

2.2 CHARACTERISTICS OF WASTEWATER.[4]

The central issue here is what Total Suspended Solids (TSS) and Biochemical Oxygen Demand (BOD) values should be considered representative of Force Provider liquid wastes.

The TSS and BOD load that could be expected in wastewater varies depending on the reference used to get the data. For example, the reference that was used in two previous studies[5,6] cited typical TSS and BOD values as follows:

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4 Descriptions of the Force Provider characteristics in this section are drawn from the same four references listed under footnote 3 in the preceding section.

5 Martel, C. J., et al, *Initial Evaluation of Geotextiles for Wastewater Filtration at Temporary Base Camps*, 1999.

	Combined Community Wastewater	Combined Household Wastewater	Separated Household Graywater	Separated Household Blackwater
TSS	200 mg/l	376 mg/l	162 mg/l	77 mg/l
BOD	200 mg/l	435 mg/l	149 mg/l	90 mg/l

Table 2-1. TSS and BOD Values for Various Types of Wastewater. [7]

Most references, including the one in column 1 above, cite 200 mg/l as the value to expect for TSS and BOD in wastewater but this value is usually representative of wastewater entering the municipal treatment facility. It is a combination of graywater, blackwater, and water leaking into the sewer, and, in some cases, it can be diluted with stormwater. The TSS and BOD values listed in Table 2-1, column 2, for household wastewater represent the combined graywater and blackwater that leaves a house. As might be expected, the values are higher because there is no leakage or stormwater factored into these parameters. The values shown in Table 2-1, columns 3 and 4, for graywater and blackwater are from samples of septic tank effluent in a system where the two streams were separated. These values are lower than the household values probably because some of the organic content was removed in the septic tank.

The TSS and BOD parameters for blackwater and graywater during an operation test of a Force Provider unit[8] have the following values:

	Graywater Storage	**Blackwater Storage**
TSS	54 mg/l	1500 mg/l
BOD	310 mg/l	2800 mg/l

Table 2-2. TSS and BOD from Force Provider Field Test.

The high values for TSS and BOD in the blackwater storage container probably reflect the small amount of flushing water (about 2 liters per flush) applied. The test report stated the TSS value for graywater storage was considered to be comparable to typical values as listed in Table 2-2. However, it is believed that the TSS is lower than the expected value probably because of less garbage being injected into the wastewater. For example, if the garbage was hauled away with the solid waste, it would make the TSS value lower. There was insufficient information in the report to determine the cause of the lower TSS value.

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6 US Army Environmental Hygiene Agency report *Wastewater Management Study No. 32-24-H26K-94 Force Provider Demonstration Project Fort Bragg, North Carolina, 1-19 November 1993*, dated May 5, 1994.

7 Solvato, Joseph A., *Environmental Engineering and Sanitation, 3rd Ed.*, Wiley and Sons, New York, 1982.

8 US Army Environmental Hygiene Agency report *Wastewater Management Study No. 32-24-H26K-94 Force Provider Demonstration Project Fort Bragg, North Carolina, 1-19 November 1993*, dated May 5, 1994.

For purposes of this study, it would seem appropriate to assume that the TSS and BOD for a fully operational Force Provider module will resemble that shown in Table 2-2 except that graywater TSS is assumed to be 300 mg/l.

2.3 WASTEWATER FLOW RATES.

Design wastewater flows for Force Provider modules are 14,307 liters (3,780 gallons) per day for blackwater and 103,614 liters (27,375 gallons) per day for graywater.[9] Operational testing[10] of Force Provider modules suggests that the daily liquid waste streams are 10,600 liters (2,800 gallons) per day for blackwater and 76,000 liters (20,000 gallons) per day for graywater for a combined wastewater flow of approximately 100,000 liters per day. For this study it was assumed that the flow rates established during operational testing are the most accurate. The 10,600 liters (2,800 gallons) per day for blackwater and 76,000 liters (20,000 gallons) per day for graywater flow rates equate to each of the four latrine tanks filling up twice a day and one of the two graywater bladders filling up once each day. Conversation with the Force Provider Program Manager's office confirmed that the operational test flow rates are most representative.[11]

2.4 PROPERTIES OF GEOSYNTHETIC MATERIALS.

Geotextiles are a subgroup of the more general category of Geosynthetics. These products carry the prefix geo because they are designed for and widely used by civil engineers in conjunction with soil and rock projects. Geotextiles are formally defined[12] as "synthetic fibers made into a flexible, porous fabric" by weaving, knitting or by matting the fibers together in a random, or non-woven, manner. In this study, a specific type of geotextiles known as non-woven will be addressed. These non-woven materials are produced in a variety of ways, including , among others, felting under pressure, needle-punching and heat-bonding. These processes are well described in "Designing with Geosynthetics"[13] which is an excellent reference for those interested in the details of the physical behavior of geosynthetics. The word "fabric" will be used interchangeably in this report to refer to all non-woven geotextiles.

Non-woven geotextiles are typically used in the construction field for the separation or filtering of soils and the transmission of water. Thickness, density, manufacturing process and average opening size are the primary design variables. Non-wovens are uniquely suited to the filtration of waste due to their low cost and the fact that they were designed to both pass water perpendicular to their plane and to prevent fine particles from crossing their width. Non-wovens are primarily used by civil engineers to allow the flow of water while filtering out fine soil particles, the same purpose that primary wastewater treatment serves.

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9 TM 10-5419-2000-14, *Operator's, Unit, Direct Support and General Support Maintenance Manual for Force Provider Modules 1 through 4*, October 30, 1998.

10 US Army Environmental Hygiene Agency report *Wastewater Management Study No. 32-24-H26K-94 Force Provider Demonstration Project Fort Bragg, North Carolina, 1-19 November 1993*, dated May 5, 1994.

11 Telephone conversation with Mr. Mike Gallagher, Force Provider Program Manager, of September 28, 1999.

12 Koerner, Robert M., *Designing with Geosynthetics*, Prentice-Hall Inc., Englewood Cliffs, NJ, 1990.

13 Ibid

2.4.1 Properties

Table 2-3 presents some values for geotextile properties as supplied by the manufacturers for this study. Where dashed lines are shown, the manufacturer was unable to supply the requested information.

The first and most easily observable property of any geotextile is its thickness. The thickness of a geotextile is actually the thickness measured when it is under compressive pressure. A common pressure used to make this measurement for non-woven geotextiles is 2 kPa. A typical thickness range for geotextiles is approximately 0.25-7.5 mm[14]. Thickness is not directly related to the density of the fabric, since there are many air-filled voids included in that thickness. The specific gravity of polypropylene, the only fiber feed-stock used in the fabric considered in this study, is 0.91, implying that a solid block of the material would float. During service as a wastewater filter, the material might include its basic polypropylene, as well as water, organic solids and air within its thickness.

Tensile strength is another important property of geotextiles. As a general rule, tensile strength increases as the thickness and weight per unit area of the fabric increase. Tensile strength of the fabric is important to this study, since most of the foreseeable designs are likely to involve placing the fabric in slight tension across some sort of roller or drum. Tensile strength is the peak force a piece of fabric of standard width can withstand prior to failure.

Values for tensile strength were not easily obtained for non-woven geotextiles, since the primary purpose of these fabrics in civil engineering applications is soil separation, channeling of water, and filtration, not for reinforcing/load bearing. Thus, the tensile strength values provided by the manufacturers, shown in Table 2-3, are average values for the geotextiles listed. The manufacturers specifically would not guarantee these tensile strength values because of minor manufacturing variations in fabric density, feed stock quality, and other factors. Typical average values of tensile strength of non-wovens, as a function of fabric unit weight are listed in Table 2-4. See Appendix A for unit weights of the products used in this report.

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14 Koerner, Robert M., *Designing with Geosynthetics*, Prentice-Hall Inc., Englewood Cliffs, NJ, 1990.

Product	Thickness (mm)	Tensile Strength (kN/m)	Permittivity (sec^{-1})	Flow Rate ($l/min/m^2$)
Amoco 4504	.85	5.25	2.0	5890
Amoco 4506	1.35	7.88	1.5	4470
Amoco 4510	2.15	14.0 @ 35% elongation	1.2	3460
Amoco 4516	2.90	24.5 @ 45% elongation	.7	2035
LINQ Typar 3401	.40	58.7 (MD)[15] 68.3 (XD)[16]	.7	2241
LINQ Typar 3501	.50	73.2 (MD) 89.3 (XD)	.7	2037
LINQ Typar 3601	.48	---	.1	611
LINQ Typar 3801	.50	---	---	---
Mirafi 1100N	2.5	12.3	1.0	3056
Mirafi 1120N	3.0	14.0	.8	2648
Mirafi 1160N	3.8	17.5	.7	2037
Synthetic Industries Geotex 1001	2.5	---	1.20	3460
Synthetic Industries Geotex 1701	4.2	---	.70	2035
Synthetic Indstries Geotex 1751	---	---	.27	2035
Webtec N03	---	1.17 @ 70% elongation	2.2	6560
Webtec N08	---	1.82 @ 70% elongation	1.5	4510
Webtec N10	---	2.19 @ 70% elongation	1.2	3490

Table 2-3. Some Physical Properties of Non-woven Geotextiles.

15 MD means Machine Direction or the direction of the length of a roll.

16 XD means Cross Direction or the direction across the width of the roll.

Fabric Unit Weight	Tensile Strength Values
200 g/m^2	6 kN/m
400 g/m^2	17.5 kN/m
600 g/m^2	20 kN/m

Table 2-4. Geotextile Tensile Strength as a Function of Fabric Density.

Permittivity (ψ) is the ability of the fabric to allow flow normal (perpendicular) to the fabric's surface. Permittivity (sec^{-1}) is defined as:

$$\psi = k_n/t,$$

where k_n is the permeability coefficient (m/sec) normal to the fabric and t is the thickness (m) of the fabric. Typically, the higher the permittivity, the greater the ability of the fabric to pass water and the greater amount of smaller particles allowed to cross the plane of the fabric.

A standard index test for determining the filtration capability of a geotextile is the Apparent Opening Size (AOS) or Equivalent Opening Size (ASTM D4751). The AOS measures the smallest diameter of particle where no more than 5% of the particles pass through the fabric. It is the particle diameter the fabric will not appreciably pass. Generally speaking, fabrics with a low AOS will act as better filters, but will clog more easily and lose permeability more rapidy. Values for AOS for selected fabrics are included in Appendix A.

All of the geotextiles considered in this study share two key characteristics; they are non-wovens, and they are composed entirely of polypropylene (disregarding possible trace impurities). A thorough understanding of the chemical properties of polypropylene is essential to the efficient design of the WFU. It also provides a more complete understanding of the general nature of the fabrics and fabric behavior to be estimated under certain conditions. Polypropylene is generated by the polymerization of propylene molecules, typically using a Ziegler-Natta catalyst, which results in isotactic polypropylene. It is a hydrocarbon with little or no unsaturation (double bonds between carbons). Propylene monomers are bonded as follows:

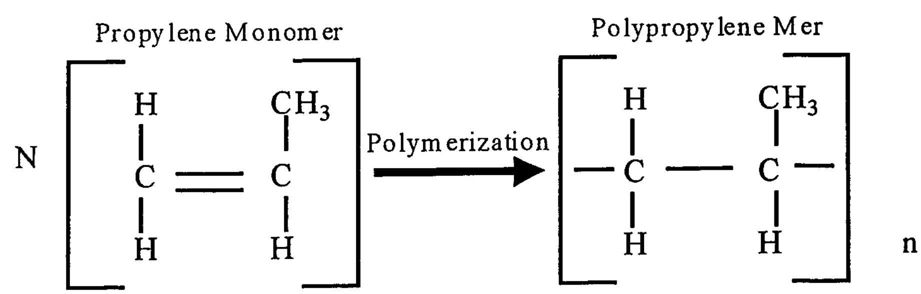

Figure 2-1. Bonding of Propylene Monomers

N bonded propylene monomers form a linear polymer chain of n mers with covalent bonds, which can be easily manipulated into a strong fiber.[17,18] For these reasons, it is important as a geotextile fiber, and polypropylene is by far the dominant material used in the manufacture of non-woven geotextiles. These fabrics are the core component of the WFU.

The specific gravity of polypropylene is in the range of 0.9 - 0.92. Significant specific heats for polypropylene are 0.46 calories per gram-degree C at 40° C and 0.5 calories per gram-degree C at 100° C (212° F).

Polypropylene has several important transition points. Its melting point is greater than 160° C (320° F). While significant, this melting point is high enough that it should not pose a problem to WFU operations. It is worth noting that melting point is not generally listed among the chemical properties of polypropylene, and has not posed significant problems in the field during construction operations. The softening point of Polypropylene is about 150° C (302° F). The softening point indicates the temperature at which significant deformation at low constant stress (high-speed creep, or a kind of taffy-like stretching) begins to take place. However, experience shows that as temperature increases, even at values less than the softening point, fabric performance will tend to degrade in terms of tensile strength, deformation under strain, creep, etc. Polypropylene's autoignition point is above 357° C (675° F).

On the lower end of the temperature range, the glass transition point of polypropylene is 0° C (32° F). Polypropylene is noticeably brittle below this transition point. This means that the operating temperature of the fabric should probably be kept between about 5° C and 60° C (41° F to 140° F). During storage, when there is no significant stress on the fabrics, these geotextiles are quite durable with regard to temperature and are fairly insensitive to freezing and high temperatures. Care should be taken to insure that the fabric is raised/lowered to proper operating temperature prior to use in the WFU.

Despite the fact that all the products tested can be generally classified as non-wovens, the manufacturing processes can vary radically. These variations will impact the cost and performance of the product. Table 2-5 lists some of the key parameters of the various fabrics used in this study. Again, where dashed lines are shown in the Table, manufacturers were unable or unwilling to supply the information. Most of the sales people contacted were receptive to providing customized lengths and widths of fabrics especially if large quantities would be involved.

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17 Van Vlack, Lawrence H., *Elements of Materials Science and Engineering*, Sixth Ed., Addison-Wesley Publishing Co., MI, 1990.

18 Koerner, Robert M., *Designing with Geosynthetics*, Prentice-Hall Inc., Englewood Cliffs, NJ, 1990.

Product	Roll Length (m)	Roll Width (m)	Roll Diameter (m)	Roll Weight (kg)	Availability of Customized Roll Size
Amoco 4504	365	4.6	---	255	---
Amoco 4506	274	4.6	---	285	---
Amoco 4510	55 or 165	4.6	---	95 or 315	---
Amoco 4516	36.6 or 91	4.6	---	105 or 255	---
LINQ Typar 3401	91.4	3.84 or /5.0	.228	58.1 or 74.9	Customized widths feasible
LINQ Typar 3501	91.4	4.75	.228	88.6	Customized widths feasible
LINQ Typar 3601	91.4	3.84 or 4.75	.254	80.8 or 100.8	Customized widths feasible
LINQ Typar 3801	91.4	4.75	.305	128	Customized widths feasible
Mirafi 1100N	91	4.5	---	150	Can cut widths in half, but cannot customize width further
Mirafi 1120N	45	4.5	---	158	Can cut widths in half, but cannot customize width further
Mirafi 1160N	45	4.5	---	114	Can cut widths in half, but cannot customize width further
Synthetic Industries Geotex 1001	91.5	4.58	.521-.635 (approx.)	140	---
Synthetic Industries Geotex 1701	91.5	4.58	.915 (approx.)	254	---
Texel 7605	150	3.5	.4	---	Width can be customized at an extra charge
Texel 425 PE 200 S	100	6.3	.6	---	Width can be customized at an extra charge
Webtec N03	110	3.8 or 4.6	---	63.5 or 77	---
Webtec N08	92	4.6	---	136	---
Webtec N10	92	4.6	---	177	---

Table 2-5. Manufacturing Specifications.

During this study, the inclusion of various stiffeners, such as wires, within the fabric was proposed/considered as a means of taking the stress of large pulling forces on the fabric. Some of the company representatives did not respond when asked if their company could accomplish this. However, the LINQ representative stated that hems could be sewn into the fabrics and wires inserted into the hems for stiffness. Whether or not this could be accomplished at their plant was uncertain. Mirafi stated that they had not previously embedded wires in the edge of fabrics, and did not say whether or not this could be accomplished as part of the manufacturing process.

Table 2-6 contains the cost data from the different companies. At the time of this report, cost data for the Amoco products were not available. The prices are current as of November, 1999 and are somewhat volatile due to the changing prices of the petroleum-based feedstock.

Fabric	Cost ($\$/m^2$)
LINQ 3401	.30
LINQ 3501	.31
LINQ 3601	.47
LINQ 3801	.53
Mirafi 1100N	1.20
Mirafi 1120N	1.50
Mirafi 1160N	1.80
Texel 7605	.75
Texel 425 PE 200 S	1.91

Table 2-6. Geotextile Fabric Costs.[19]

The company representatives we contacted are listed in Appendix A.

2.5 ENVIRONMENTAL GOALS.

This study is intended to contribute to the ultimate goal of developing a system that will permit Force Provider or similar units to treat wastewater and discharge it to local receiving waters. Therefore, it was necessary to define the water quality standards that had to be achieved regardless of the location of the Force Provider module.

19 Only the manufacturers shown provided cost information.

The regulations and doctrine researched[20] all required Commanders to ensure water discharges meet all local and national laws and regulations both at home and abroad. Because there is such a wide disparity in requirements, very few objective standards or numerical limits are provided. In the US, Commanders must be aware of Federal laws and regulations as well as the local laws and regulations that have been enacted to implement them. Overseas, Commanders are required to meet the host nation's requirements and if they don't exist then US domestic requirements apply. The most frequently noted requirement in the documentation is similar to that in the Force Provider Operational Requirements Document which stipulates that wastewater be disposed of in an environmentally safe method.

It is not the purpose of this study to get into the details of environmental laws and regulations. UTD decided to use the US Environmental Protection Agency secondary wastewater treatment standard of a 30 mg/l maximum for TSS and BOD with a total removal efficiency of 85%. Other treatment limits such as pH and fecal coliform limits and restrictions imposed by National Pollutant Discharge Elimination System (NPDES) permits are beyond the scope of this study

20 AR 200-1, Environmental Protection and Enhancement.

TM 5-814-3, Domestic Wastewater Treatment.

TM 5-814-8, Evaluation Criteria Guide for Water Pollution: Prevention, Control, Abatement.

SECTION 3

ANALYSIS

3.1 SUMMARY

For the analysis task of this project, the WFU treatment system was divided into three sections and teams formed to study the basic principles, laws, and empirical results that could be used to describe the processes in those subsystems. The subsystems are Geosynthetics, Mechanical Handling, and Incineration. Although it was not part of the original effort, biological treatment subsystems that could be used for secondary treatment were also examined.

For each subsystem, the operating and performance characteristics of the subsystem based on physical laws or empirical results were reviewed. Utilizing either theoretical or experimental behavior, a method was developed to determine the optimum configuration, flow, speed, size, and operating method for each subsystem.

UTD established an initial assumption of what a WFU might look like based on prior research and estimates of performance. The WFU initially envisioned was a totally self-contained unit with a filtration section and an incinerator. Then three parallel research paths to study Geosynthetics, Mechanical Handling, and Incineration were followed. As the study progressed the conceptual view of the whole system evolved. The evolution of the whole system is discussed in more detail in Section 4. The remaining parts of this Section describe the details of subsystem analysis and how some of the findings impacted the overall design.

3.2 GEOSYNTHETIC FILTER RESEARCH AND TESTING

Before the start of this study, a review of the considerable data[21] that had been gathered at the Army Corps of Engineers Cold Regions Research and Engineering Laboratory (CRREL) was conducted. The CRREL study strongly indicated that geotextiles could act as cost-effective and highly efficient wastewater filters. Specifically, experiments indicated that geotextiles were effective at reducing total suspended solids (TSS) by about 60% and BOD by about 40%, given raw wastewater with initial TSS and BOD of 137mg/l and 276mg/l, respectively. The hydraulic capacity of the geotextiles determined in that study varied between 500 and 3100 l/m^2, depending on the properties of the waste stream being filtered. The CRREL study indicates that the hydraulic capacity tended to decrease as the TSS level increased.

To design an efficient WFU and to determine critical design parameters such as the time rates of filtration, additional testing was undertaken by the Catholic University team to supplement the CRREL study. Specifically, two key design issues were examined:

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21. Martel, C. J., et al, *Initial Evaluation of Geotextiles for Wastewater Filtration at Temporary Base Camps*, 1999.

- The effect of varying the pressure drop across the filter. Specifically, the effect of added head on the influent (upstream) side of the filter vs. increase in flow rates, and the effect on filter efficiency and TSS and BOD reduction.

- Time dependency of flow and the rate at which the filters must be changed out (or fed through the system) in order to optimize WFU performance.

To address these issues, 20 field trials were made at District of Columbia's Blue Plains wastewater treatment plant. Variables in these trials included influent characteristics, pressure on the upstream side of the filter, and filter type. During each test influent characteristics, flow rate, and filtrate characteristics were measured. Details of the experiments conducted and analysis of the results are included in the following sections.

3.2.1 Major Findings

- The needle-punched geotextile fabrics (the Mirafi and Amoco products) are capable of filtering in the range of 2,000 l/m^2 of wastewater. This is in excellent agreement with the study by Martel[22] and indicates great suitability for the proposed WFU.

- The fabrics were excellent at TSS removal and adequate for the reduction of BOD.

- The melt-bonded products (manufactured by LINQ) are less suited to the proposed application, but may still be candidates for use due to their very low comparative weight and cost.

- A good first-order approximation of the generalized behavior of the geotextile filters at moderate TSS levels can be made through a simple log relationship.

- The TSS concentrations of the incoming waste stream at Blue Plains did not strongly impact the behavior of the geotextile filters. In fact, the filters were surprisingly insensitive to changes in TSS.

- There is a strong indication that the presence or lack of particles in a very narrow size range (close to perhaps 0.1mm in diameter) is a primary driver of filter performance. Therefore, a simple evaluation of TSS levels is not sufficient for fully quantifying expected filter behavior. Future studies should include a careful examination of particle size.

3.2.2 Characteristics of the Influent at Blue Plains.

Before proceeding with a description of the experiments conducted, a description of the character of the wastewater used for these experiments and especially its inherent variability is required.

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22 Ibid.

All experiments conducted for this study used untreated wastewater, sometimes called primary influent, collected from the screening chamber at Blue Plains. The screening chamber is the entry point for wastewater at the facility. The level of water in the chamber varied daily according to the amount of rainfall and groundwater entering the system.

When examining the results in the following sections, it is necessary to remember that the wastewater examined in this study comes from a combined wastewater collection system. This means that the sewer system in the District of Columbia collects blackwater and graywater (as is usual for municipal wastewater treatment systems) as well as some stormwater. This stormwater enters the system from street-level collection basins and from infiltration of groundwater into buried sewer pipes. Thus, the fundamental character of the wastewater stream varies according to recent precipitation. More rain typically means higher grit or sand loads and lower BOD levels, but this can also vary depending on the frequency and magnitude of recent rainfall. The key consideration is that the concentration, particle size, and chemical makeup of the solids entering Blue Plains is not a constant, and each set of test results must be considered in light of the waste stream characteristics on that particular day. For instance, TSS levels varied between 45 and 227mg/l over the course of the five weeks during which this study was conducted. Consideration of these variations is particularly important when trying to directly compare data collected on different days. Influent data are summarized in Table 3-1.

Date	Time	TSS, mg/l	Temp., ^{0}C	pH	BOD, mg/l
10/29/99	10:17 a.m.	227.0	11.7	7.1	- -
10/29/99	3:10 p.m.	126.0	11.7	7.2	- -
11/3/99	11:00 a.m.	58.0	11.7	7.2	- -
11/3/99	3:15 a.m.	77.3	11.7	7.1	- -
11/5/99	2:30 p.m.	68.0	11.7	7.4	- -
11/5/99	4:00 p.m.	80.0	- -	- -	- -
11/12/99	8:40 a.m.	51.3	11.4	7.4	- -
11/12/99	2:10 p.m.	45.5	11.7	7.3	- -
12/1/99	Morning	164.0	11.7	7.2	185
12/1/99	Afternoon	112.0	11.1	7.2	145

Table 3-1. Influent Data from Blue Plains.

From a practical point of view, the waste stream at Blue Plains is different from the expected waste stream in a Force Provider Unit in several important ways, including the presence of stormwater runoff and somewhat lower TSS and BOD concentrations than those cited in Section 2.2.

3.2.3 Experimental Apparatus and Methods

This section describes in some detail the experimental apparatus and methods used to conduct this study. From a philosophical point of view, keep in mind that the primary goal was to gather fundamental data for the conceptual design of real equipment. Therefore, data that would be scientifically interesting but would not impact the design process were not gathered. For instance, a clear idea of the particle size distribution in the influent would have been a necessity for an analytical evaluation of the filtering process on the micro-scale. This key variable would be the sort of additional data that would allow the design of the WFU to be further refined as part of Phase II of this project.

A schematic drawing of the Filter Test Apparatus (FTA) is shown in Figure 3-1. A photo of the FTA in operation is shown in Figure 3-2.

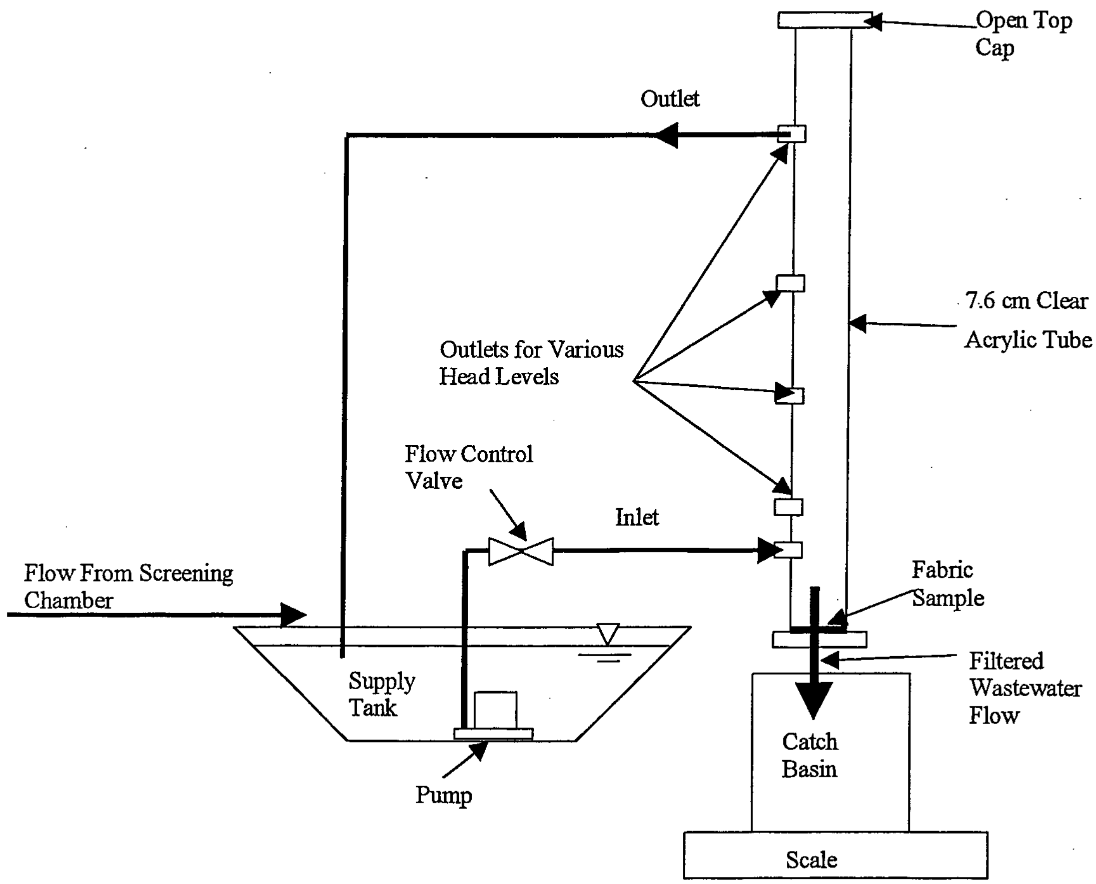

Figure 3-1. Filter Testing Apparatus

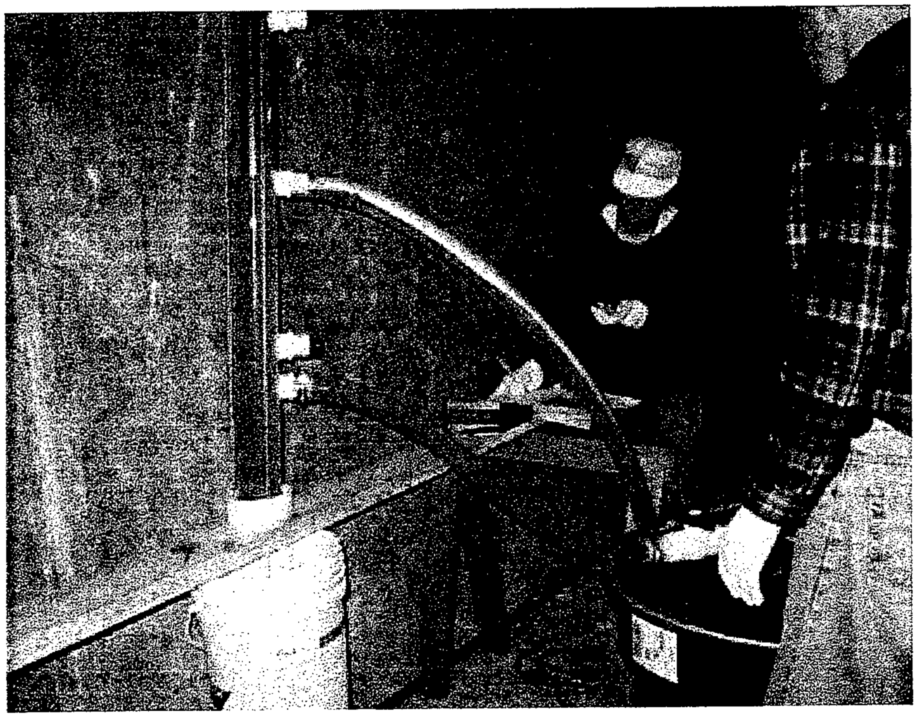

Figure 3-2. A Filter Test in Progress.

Key components of the FTA operation include the following:

- The 76mm (3 inch) acrylic stack was held vertical with the filter at the bottom. The stack was penetrated at 0.2m, 0.3m (1 foot), 0.6m (2 foot), 0.9m (3 foot) and 1.2m (4 foot) levels above the filter by 38mm (1.5 inch) diameter flow ports. The 0.9m port was not used in these experiments.

- The raw influent flowed in through the 0.2m inflow port and flowed out through the filter fabric and/or an overflow port. Flowing wastewater that did not pass through the filter flowed out through whichever of the other ports was opened to flow by the operator. This scheme allowed for a constant head of 0.3, 0.6, or 1.2m to be maintained on the upstream side of the filter fabric.

- To control the flow rate, a flow control valve was included on the influent side in-line between the pump and the stack. Typically, the operator opened and adjusted this valve to maintain appropriate head level at the start of the test and did not modify its position until the conclusion of the experiment.

- All wastewater fed into the system that did not pass through the filter was recirculated back into the supply tank via the overflow port and return flow line.

- The volume of water that passed through the filter fabric was determined indirectly via weighing. It was assumed that 1 liter of water had a mass of 1kg. While this is slightly incorrect given the presence of solids, the error is very minor. For example, for a TSS level of as much as 500mg/l, there is 0.5g/l of solids in the water. Assuming a specific gravity of 2.7 for the solids, this equals about 0.19cc of solids per l of wastewater. This resolves to a mixture density of 1.00031kg/l, an error of only 0.031%. The real error is even less than this, since the typical TSS experienced was far below 500mg/l.

3.2.4 Experimental Goals and Procedures

The principal goals were to quantify the behavior of the filters as a function of time and to measure the effect of variations in the pressure on the upstream side of the filter fabric. The data gathered and the methods used are summarized and described below.

- To quantify the character of the influent, wastewater samples were taken from the supply tub immediately after filling and pH and temperature were recorded. The samples were subsequently analyzed for TSS. Samples were also taken at the end of each day of testing immediately prior to running the last experiment of the day. While BOD samples were taken simultaneously, the analytical lab felt the samples were too old for a reliable analysis to be performed. Therefore, BOD data exists for one day of testing. Data related to the influent is listed in Table 3-1.

- During each experiment, a log of mass and time was kept. Plots of the flow versus time for each experiment are included in Appendix B.

- At the conclusion of each experiment, a sample of the filtered water was taken and pH was recorded. The sample was subsequently analyzed for TSS. BOD analysis is available for one day of testing. This data is presented and discussed in the analysis subsection.

Each day of experimentation began with setting up the equipment and pumping a sample from the plant influent into our supply tub. Pumping was accomplished using a high-flow, low-head pump and hose capable of passing large (>1 cm) particles whole. Depending on the level of water in the plant's screening chamber, the filling took between 5 and 15 minutes, during which time the first filter fabric sample was mounted at the base of the stack. The influent sample was then homogenized by stirring the wastewater in the supply tub with a long 38 mm (1.5 inch) PVC pipe. Immediately after homogenization, the initial influent TSS and BOD samples were taken and placed on ice. Temperature and pH of the influent were also measured at this time.

With the flow control valve closed, the supply tub pump was turned on and the 38 mm hoses were attached to the appropriate flow ports (supply and return). The fabric type and planned head level were then recorded and the scale and timer zeroed. The flow control valve was opened and adjusted to get the desired head, and the total mass of filtered water and time elapsed was recorded. Flow was allowed to continue until little or no change in the flow rate was observed or the rate of flow fell below about 0.1 liter per minute. At test termination, the supply pump was turned off and the stack was drained. The collected filtrate was then homogenized and samples for TSS and BOD were collected and put on ice. The pH of the filtrate was also measured at this time, but no significant change in pH due to filtration was ever noted. At the conclusion of filtrate sampling, the remaining filtrate was discarded into the plant screening chamber and the stack was washed down with clear water and a new sample was mounted for the next experiment. The FTA was then ready for the next test, which would be conducted using the same supply tub influent sample as was used for the previous experiment.

In all cases, a single influent sample was taken at the beginning of the day of testing and used for all tests conducted that day. A second TSS and BOD sample of the influent in the supply tub was taken at the end of each day of testing to check variation of TSS and BOD in the tub during the day. While the values were found to vary by as much as 30% over the course of a day of testing, there was not a consistent variation in TSS over time. This is probably due to variations in the energy used to stir the sample for homogenization just prior to taking the sample. Grit about 2mm in diameter will tend to settle very quickly, so a very minor variation in the time between stirring and sampling could lead to significant changes in TSS levels. It is assumed that the 500ml sample is representative of 250+ liter sample tub. Further, while only about 10 liters of wastewater passed through the filter in each test, the re-circulating nature of the apparatus means that perhaps 200l of sample were pumped into the stack as part of each experiment.

3.2.5 Data Summary

The data collected using the FTA at Blue Plains are summarized in Table 3-2. As mentioned previously, the complete flow data for each individual filter experiment are shown in Appendix B. The first column of Table 3-2 lists the fabric manufacturer geotextile type. Head level is the height of the wastewater in the stack above the filter. We controlled head level by maintaining flow out of the column at the appropriate return port. TSS_{in} and TSS_{out} are the Total Suspended Solids contents in the influent and filtrate, respectively; similarly, BOD_{in} and BOD_{out} represent the Biochemical Oxygen Demand (BOD_5) in the influent and filtrate. Flow at ten minutes, the final column in Table 3-2, is the total amount of filtrate passing through the filter in ten minutes, normalized to one square meter of filter fabric.

Flow was normalized to ten minutes to allow for a direct comparison of different fabrics. Ten minutes probably represents a filter residence time somewhat in excess of optimum, but the ratio of total flow at ten minutes to other time intervals (i.e., three minutes) is relatively constant, so ten minutes is appropriate for the purposes of comparison.

Table 3-3 contains much of the same data as Table 3-2, but it is organized by date and also includes influent, TSS removal efficiency, and solids capacity data. Table 3-3 is in some ways more useful because it takes into account the variations in influent properties from day to day. As previously mentioned, since the collection system combines stormwater and wastewater, the wastewater TSS and BOD entering the plant is not the same from day to day. This is clearly illustrated in the variation of TSS data over time. The solids capacity data is an indicator of the total solids removed from the wastewater by the filter in the course of an experiment. This was computed as the TSS_{in} less the TSS_{out} multiplied by the number of liters filtered in 10 minutes. Solids capacity was calculated because it was hypothesized to be constant or that it could be correlated to head level. This turned out not to be the case.

Fabric Brand and Type	Wastewater Head Level, m	TSS_{in}, mg/l	TSS_{out}, mg/l	BOD_{in}, mg/l	BOD_{out}, mg/l	Cumulative Flow for 10 min, l/m^2
Mirafi						
1120	0.3	51.3	9			2384
1120	0.6	58	18			1673
1120	0.6	164	49	185	100	2191
1120	1.2	77.3	5.5			2046
1160	0.3	51.3	5.5			2482
1160	0.6	58	12			1903
1160	0.6	112	52	145	92	2213
1160	1.2	58	36			1947
LINQ						
3501	0.3	51.3	8.5			1596
3501	0.6	164	48	185	98	1680
3501	1.2	80	21			1079
3601	0.3	51.3	10			1498
3601	1.2	68	23.3			1246
3801	0.3	45.5	22			452
3801	0.6	164	90	185	79	289
3801	0.6	227	50			230
3801	1.2	68	14			888
Amoco						
4510	0.3	51.3	9.5			2096
4510	0.6	164	57	185	92	2099
4510	1.2	68	35.3			1366

Table 3-2. Summary of Geotextile Performance Data by Filter Type.

3.2.6 Data Analysis

One of the fundamental purposes of this experimental program was to quantify the behavior of the geotextile filters with respect to time. In this respect, the fabrics were found to be relatively consistent in their behavior and could be generally modeled using simple mathematical relationships. The raw data contained in Appendix B is presented against arithmetic scales, but a plot of any of the flow data against the log of time results in a fairly linear relationship. Thus, the behavior of any of the filters can be roughly modeled by:

$$V_{filtrate} = V_1 + C_f(\log t)$$

where

$V_{filtrate}$ = the volume of filtrate passing through 1 square meter of fabric.

V_1 = the volume passing in 1 minute (an experimentally measured constant).

C_f = the flow constant (experimentally measured).

t = time in minutes.

Fabric or Sample Type	Date	Test Catalog Number	Head Level m	TSS_{in} mg/L	TSS_{out} mg/L	Water Passed in 10 minutes L/m^2	Solids Capacity g/m^2 in 10 min	TSS Removal Efficiency %
LINQ 3801	29-Oct	L-3 F	0.6	227.0	50.0	230	52	78.0
Influent	29-Oct	L-4 UF		126.0				
Influent	29-Oct	L-2 UF		227.0				
Initial Influent	3-Nov	Start UF		58				
Mirafi 1120 N	3-Nov	M-1 F	0.6	58.0	18.0	1673	97	69.0
Mirafi 1160 N	3-Nov	M-2 F	0.6	58.0	12.0	1903	110	79.3
Mirafi 1160 N	3-Nov	M-3 F	1.2	58.0	36.0	1947	113	37.9
Mirafi 1120 N	3-Nov	M-4 F	1.2	77.3	5.5	2046	158	92.9
Final Influent	3-Nov	End UF		77.3				
Initial Influent	5-Nov	Start UF		68.0				
Amoco 4510	5-Nov	A-4 F	1.2	68.0	35.3	1366	93	48.1
LINQ 3601	5-Nov	L-5 F	1.2	68.0	23.3	1246	85	65.7
LINQ 3801	5-Nov	L-6 F	1.2	68.0	14.0	888	60	79.4
LINQ 3501	5-Nov	L-7 F	1.2	80.0	21.0	1079	86	73.8
Final Influent	5-Nov	End UF		80.0				
Initial Influent	12-Nov	Start UF		51.3				
Amoco 4510	12-Nov	A-5 F	0.3	51.3	9.5	2096	108	81.5
Mirafi 1120 N	12-Nov	M-5 F	0.3	51.3	9.0	2384	122	82.5
Mirafi 1160 N	12-Nov	M-6 F	0.3	51.3	5.5	2482	127	89.3
LINQ 3501	12-Nov	L-8 F	0.3	51.3	8.5	1596	82	83.4
LINQ 3601	12-Nov	L-9 F	0.3	51.3	10.0	1498	77	80.5
LINQ 3801	12-Nov	L-10 F	0.3	45.5	22.0	452	21	51.6
Final Influent	12-Nov	End UF		45.5				
Initial Influent	1-Dec	Start UF		164				
Amoco 4510	1-Dec	A-6 F	0.6	164	57	2099	344	65.2
LINQ 3501	1-Dec	L-11 F	0.6	164	48	1680	275	70.7
LINQ 3801	1-Dec	L-12 F	0.6	164	90	289	47	45.1
Mirafi 1120 N	1-Dec	M-7 F	0.6	164	49	2191	359	70.1
Mirafi 1160 N	1-Dec	M-8 F	0.6	112	52	2213	248	53.6
Final Influent	1-Dec	End UF		112				

Table 3-3. Summary of Influent and Filter Testing Data by Date.

Values for C_f and V_1 for each brand of fabric for different experiments were calculated, averaged, and are tabulated below.[23]

Date, Head Level	Mirafi 1120	Mirafi 1160	Amoco 4510	LINQ 3501	LINQ 3601	LINQ 3801
Values of C_f						
10/29, 0.6 m						95
11/3, 0.6 m	800	925				
11/3, 1.2 m	783	1000				
11/5, 1.2 m			350	383	500	433
11/12, 0.3 m	1350	1000	1100	950	950	300
12/1, 0.6 m	1250	1100	950	770		120
Average Value	1046	1006	800	701	725	237
Values of V_1						
10/29, 0.6 m						135
11/3, 0.6 m	900	950				
11/3, 1.2 m	1250	1000				
11/5, 1.2 m			1000	750	750	450
11/12, 0.3 m	1000	1500	1100	600	550	150
12/1, 0.6 m	950	1050	1500	900		150
Average Value	1025	1125	1200	750	650	221

Table 3-4 Variations in C_f and V_1 with Date and Fabric Type.

The values of both C_f and V_1 in Table 3-4 are relatively constant regardless of head level and TSS of the influent. Therefore, average values of C_1 and V_1 for each fabric were used to make a plot of filter performance for that fabric. The data fit illustrated for the Mirafi 1120 in Figure 3-3 is not a perfect fit but it does adequately model filter performance for analysis. The lack of particle size data, which is probably the fundamental driver of filter performance must be analyzed in follow-on studies.

Previous experiments using geotextiles as wastewater filters indicated that TSS was a key variable in determining the volume of wastewater that could be processed prior to filter clogging.[24] In those experiments, the TSS level was varied by sampling the same wastewater after allowing certain time for settlement of solids from the primary effluent or by sampling at different places in the treatment train. This previous data strongly indicate that particle sizes in the range of those that settle out in the first few minutes are most involved in plugging the filters.

23 In Section 3.3, we used an exponential function and made a good least squares fit of data from one experiment.

24 Martel, C. J., et al, *Initial Evaluation of Geotextiles for Wastewater Filtration at Temporary Base Camps*, 1999.

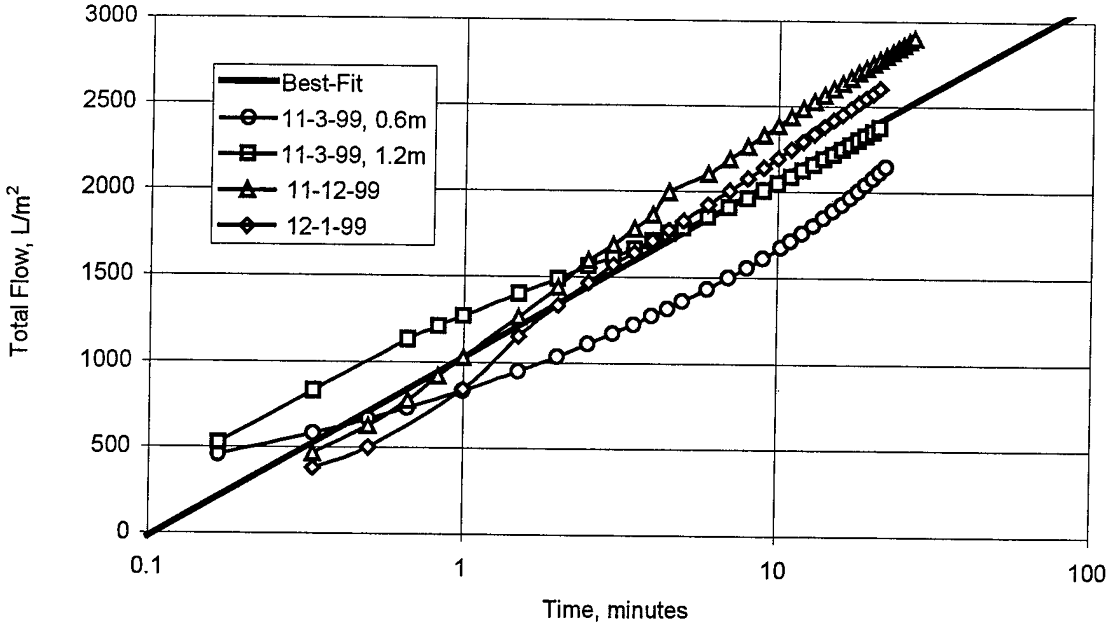

Figure 3-3. Best Fit for All Mirafi 1120 Data.

For instance, given 15 minutes of settling prior to filtering, Martel[25] found that the influent TSS fell by about 50%, but the filtrate TSS did not change. Further, the volume of influent needed to clog the filter increased significantly as the influent TSS fell. From this, it can be concluded that the material in the filtrate has very small particle sizes, less than 0.1 mm, which is not likely to settle out or to clog the filter. Conversely, the material most likely to clog a filter with an average opening size (AOS) of around 0.1 mm would be the material just slightly larger than the AOS, or fine sand. Fine sand would tend to settle out of still wastewater very quickly (certainly in less than 15 minutes). This leads to the hypothesis that it is the particle size distribution of the incoming waste stream that drives filter performance. In theory, a very small amount of incoming waste in just the right size range could plug the filter. This is consistent with the general rules of soil mechanics, which state that less than 10% of the total sample by weight can drive the permeability behavior of entire soil strata.[26] Thus, the following insights from a combination of the previous study and general geotechnical findings related to permeability are drawn:

- Geotextiles are highly effective wastewater filters that will perform well as a primary treatment method and in removal of solids from secondary effluent.

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25 Ibid.

26 Das, Braja M., *Principles of Geotechnical Engineering*, 4th Ed., PWS Publishing Co., Boston, MA, 1998.

27 Martel, C. J., et al, Initial Evaluation of Geotextiles for Wastewater Filtration at Temporary Base Camps, 1999.

- Little or no advantage is likely to be gained in terms of TSS removal by adding geotextile filters in combination with primary settlement or flocculation. No significant TSS effluent changes were noted after allowing settling, despite large changes in influent TSS levels. In other words the particles most likely to be captured by filtration had already been removed by settling.

- Filtration of a biological secondary treatment process is likely to generate a TSS reduction because of larger particles in the effluent that could be attributed to sloughing of microbial growth.

- The clogging of geotextile filters is probably driven by the presence of particles within a fairly narrow size range. Larger particles will tend to sit atop the filter, rather than embed within it, and slow down flow. Smaller particles will pass through the filter without clogging it.

These insights were developed from consideration of the previous study [27] supported by the experiments conducted as part of this study. Multiple attempts were made by the UTD-Catholic University team to find a fundamental relationship between flow and head levels, influent TSS levels, geotextile permittivity, removal efficiency, etc. As is clearly illustrated in Figure 3-4, strong relationships between these variables were not observed. Figure 3-4 presents data from different experiments on different days under different head levels, and illustrates that various fabrics seemed to be relatively insensitive to changes in TSS and head level. This can also be seen through a careful examination of the data summary tables. In combination with the CRREL data, this leads to the conclusion that influent particle size, not measured in this Phase I study, is a primary driver of filter performance.

An examination of the TSS and BOD data in Tables 3-2 and 3-3 shows that the geotextile filters were highly suitable for the removal of TSS, rarely removing less than 50% of the solids load. In many cases, the removal efficiency was much higher than 50%, particularly at low head levels. However, head level was not a strong driver of TSS removal efficiency. In the case of BOD removal, the fabrics were somewhat less effective, removing about 50% of the BOD, depending on fabric type. However, since a secondary treatment system is a near certainty, high BOD is not of as much concern as high TSS would be. In summary, the fabrics were excellent at TSS removal and adequate for the reduction of BOD.

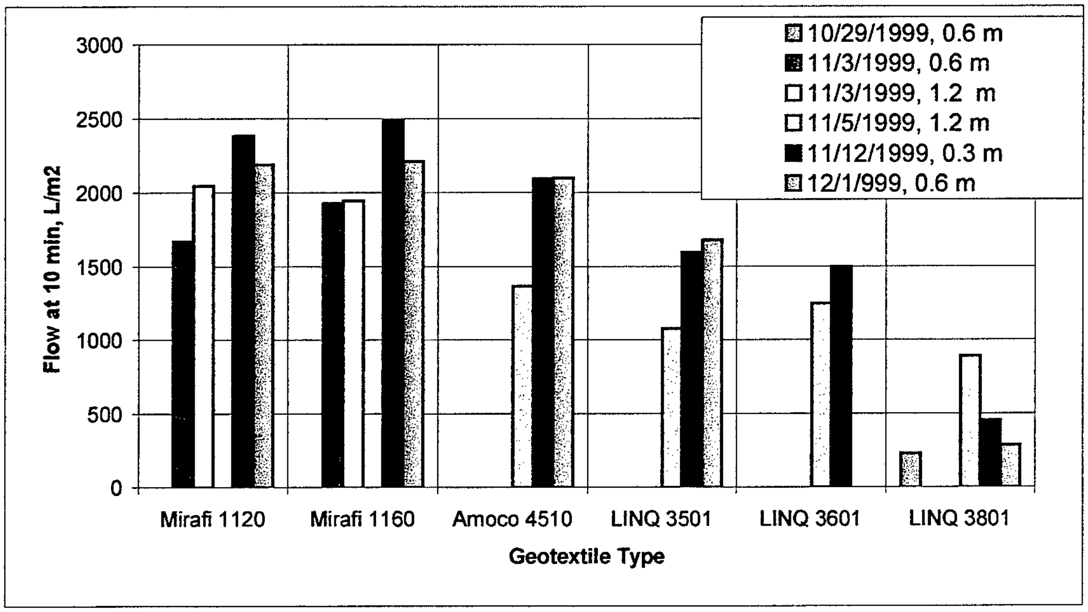

Figure 3-4. Flow at 10 minutes by Geotextile Type and Date of Testing.

3.3 MECHANICAL HANDLING SUBSYSTEM STUDIES.

3.3.1 Major Findings.

- Based on experimental filtration results, a WFU is estimated process (equivalent to conventional primary treatment) a Force Provider latrine tank in about 36 minutes twice a day and use about 1 square meter of fabric during each process cycle.

- Based on experimental filtration results, a WFU will process (equivalent to conventional primary treatment) the entire Force Provider liquid waste stream in about 13 hours each day and use about 60 square meters of fabric during the filtration process cycle. A secondary treatment process would take about the same length of time and consume about as much fabric.

3.3.2 Discussion.

The original concept envisioned for moving the geotextile fabric through the filter assembly is depicted in Figure 3.5. A thorough discussion of this system is provided followed by the system modifications instituted.

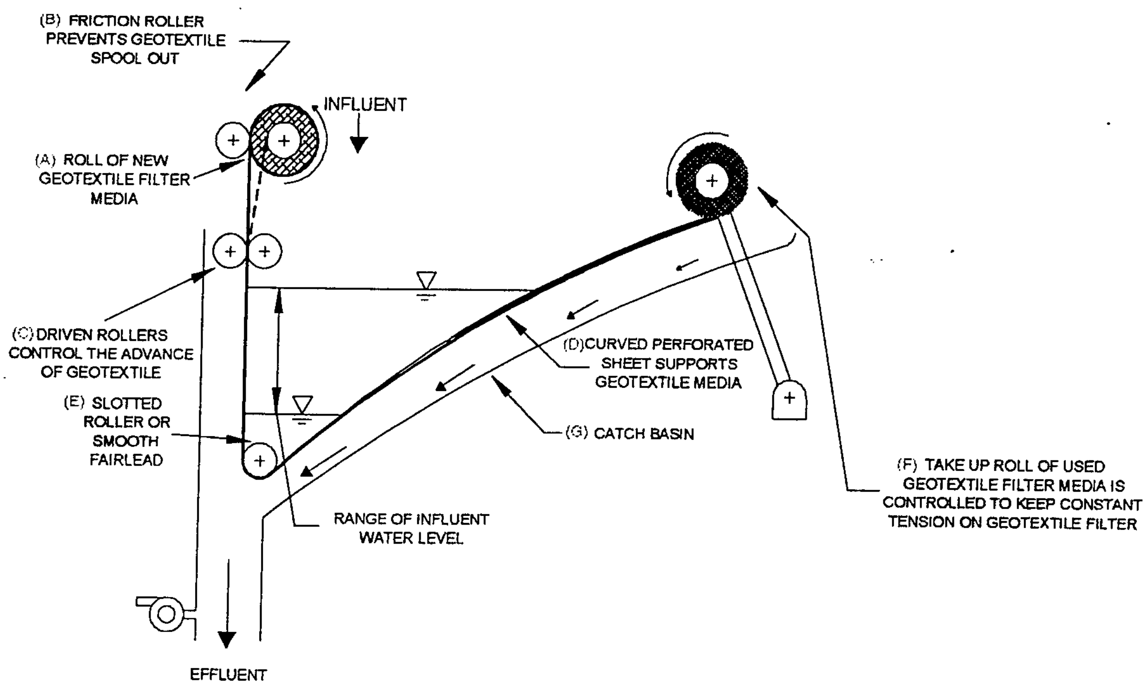

Figure 3-5. The Original Concept for the Filtration Tub.

The essential feature of the original concept was to keep the fabric in tension as it passes over a curved perforated surface. The tension serves to provide sealing pressure so that the water to be filtered does not follow a hydraulic short circuit around the fabric. With the fabric firmly pressed against the perforated tub, the water passes through the fabric and then through the tub perforations. There were several issues that had to be analyzed to fully understand the mechanics of this concept.

The issues to be analyzed include 1) how does the fabric tension effect sealing pressure, 2) how does the tub curvature effected fabric tension, and 3) what coefficient of dynamic friction is applicable. The approach adopted was to model the process after a friction belt and pulley arrangement shown in Figure 3-6.

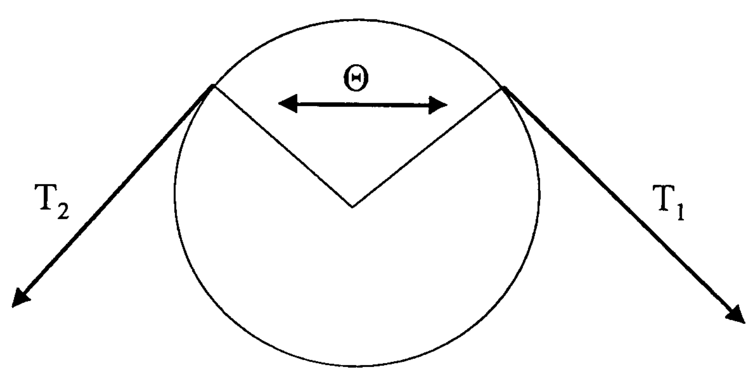

Figure 3-6. Friction Belt and Pulley Model.

In Figure 3-6. there is no slip between the belt and the pulley. In such an arrangement, the belt tension is different on either side of the pulley. If the belt is driving the pulley, the belt tension is highest on the side in the direction of motion. If the pulley is driving the belt, the tension is highest in the belt that is away from the direction of motion. In either case, the relationship[27] between the parameters is given in equation 1:

$$\frac{T_1}{T_2} = e^{\mu\theta} \qquad (1)$$

For the case where the belt is driving the pulley, T_1 is the tension in the pulling side of the belt while T_2 is the tension in the "slack" side of the belt. θ is the angle of contact that the belt makes with the pulley, measured in radians. The coefficient of friction between the belt and the pulley is μ. This relationship is derived from equations for the balance of forces under conditions where the belt is just about to begin slipping. For the situation where the belt is slipping across the pulley, the same relationship can be used as long as μ is the dynamic coefficient of friction.

Some useful corollaries of equation (1) are provided in equations 2a and 2b:

$$p_{\max} = \frac{2T_1}{Db} \qquad (2a)$$

$$p_{\min} = \frac{2T_2}{Db} \qquad (2b)$$

In equation 2a, the pressure exerted on the pulley at the point of greatest belt tension (T_1) is p_{max}. D is the diameter of the pulley and b is the width of the belt. Just as the tension in the belt decreases through the angle of contact, the pressure on the pulley decreases. The minimum pressure, expressed in equation 2b, occurs at the point of least tension.

With the relationships discussed above, the "tub analysis" begins with an estimate of the hydrostatic pressure likely to be encountered at the fabric – tub interface. Setting p_{min} in equation (2b) equal to the greatest hydrostatic pressure then the pressure at all points along the fabric - tub interface will be equal to or greater than the hydrostatic pressure. This will minimize hydraulic short circuits. Then, letting T_1 equal the tensile strength of the fabric divided by an appropriate factor of safety, equations (1), (2a), and (2b) can be used to evaluate the tub diameter, fabric width, and angle of contact.

An experiment to find the dynamic coefficient of friction for use in equation (1) was conducted. A piece of geotextile fabric was placed on a stainless steel surface, with a known weight or normal force on top of the fabric. The fabric was then pulled with a scale to measure the pulling force. The results indicated that .3 is a good value to use for μ in equation (1).

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[27] Shigley, Joseph E., Mechanical Engineering Design, 3rd Edition, McGraw Hill, New York, NY, 1977.

During the tub analysis a variety of tub configurations were examined with variations in the tub diameter, angle of contact, and the flow of wastewater across the fabric – tub interface. Some of these configurations are shown in Appendix C. The designs provided in Appendix C presented several issues that required resolution, i.e., 1) placing the filter behind the perforated wall which reduces the efficiency of solid cake build-up on the moving filter causing particle collection in the wall perforations; 2) reverting the flow to realize the benefits of gravity; 3) eliminating the submerged moving parts such as rollers and bearings; 4) eliminating the direct stress on the filter material to prevent degradation of filter material performance.

The configuration ultimately chosen is shown in Figure 3-7 and incorporates corrections to all these concerns. The central feature of this configuration is the reinforcement of the fabric edges with nylon straps and the use of metal guides to keep the fabric in place. The geotextile will feed from roll (A) shown on the far left of Figure 3-7. Initially the filter is threaded into and through the smooth guides (B) and onto the take-up roll (C). The wastewater flows into the WFU and filters through the active window of filtration (D). The take-up spool winds up the used geotextile filter after it is fed through the curved tub basin (E). The tensile strength of the filter is reinforced by the addition of nylon straps (F) sewn to each side of the filter fabric. The reinforcing nylon straps are fed through the guides of the curved tub basin to provide a means of holding the filter in place during the filtration process. Addition of the nylon straps allows tension to be applied without distorting the fabric and altering its filtration properties. If the tension were applied directly to the filter fabric rather than through the nylon straps, the result would cause a change in the filter microstructure thereby changing the filtration properties of the geotextile. Another benefit resulting from the addition of the reinforcing nylon straps is that a small space, on top of the fabric and between the nylon guides, is created for the collected wastewater sludge. Figure 3-8 shows the space in an exaggerated view. This added space reduces the squeezing effect on the collected sludge when the filter and entrained waste are wound onto the take-up spool.

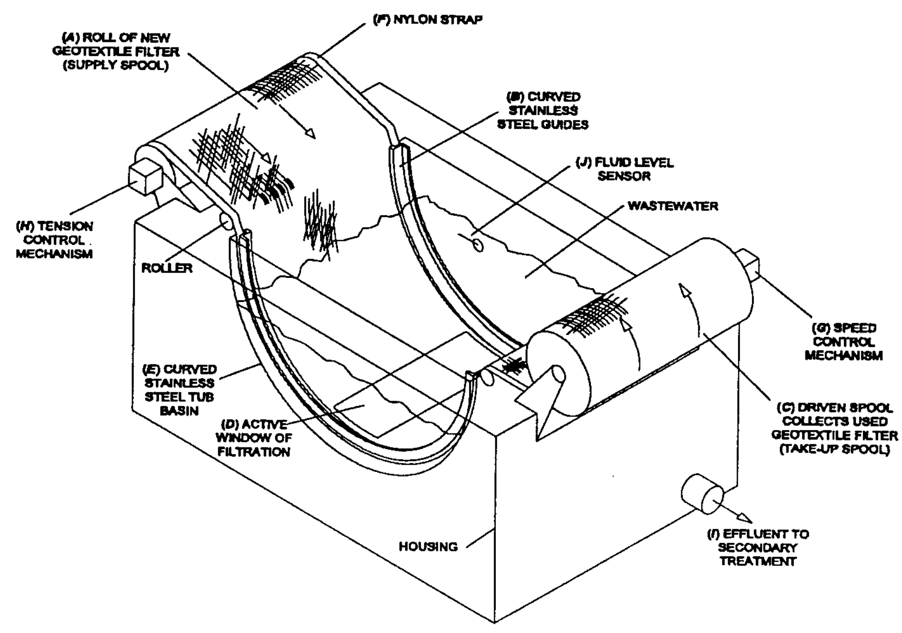

Figure 3-7. Wastewater Flows Downward across Fabric that is Reinforced and Channeled.

If the minimum pressure exerted on the cylindrical guides by the straps as expressed by equation (2b) is set equal to the maximum hydrostatic pressure, a good seal can be obtained. This would provide a factor of safety since the point of greatest hydrostatic pressure is at the bottom of the curved surface where the sealing pressure would be between the maximum and minimum.

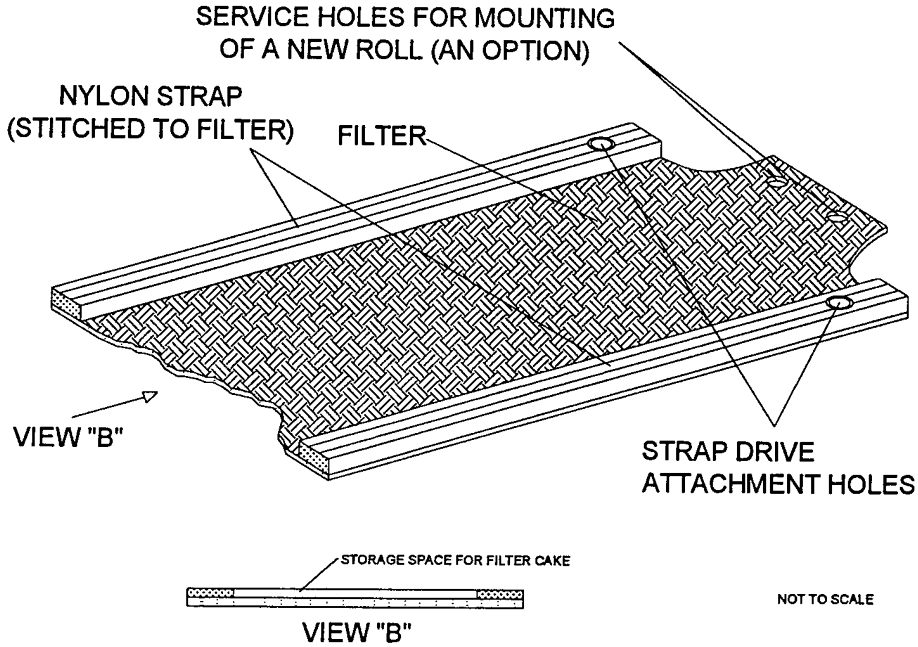

Figure 3-8. Space between the Nylon Straps and the Fabric.

The point of maximum depth of strap in the wastewater is located at the bottom of the cylindrical guides which for example might be set at $D/2 = 2$ feet. At 2 feet of depth, the hydrostatic pressure of the wastewater is about 0.87 psi. Setting the width b of the nylon strap at 2 inches, using equation (2b), the resisting strap branch tension T_2 is found to be about 42 lbs. It was assumed that the coefficient of friction between the nylon strap and the cylindrical metal guides is roughly the same as the experimentally determined value of about 0.3. Given the approximate angle of contact between the straps and the cylindrical metal guides 180^0 (π radians), using equation (1), the tension in the pulling branch is around 107 lbs. Therefore, a minimum strap tension of 107 1bs must be maintained on the pulling-branch of the straps so as to assure sufficient strap pressure on the cylindrical metal guides to prevent wastewater seepage along the filter edges.

Referring to Figure 3-7, as the take-up spool (C) collects the sludge covered filter, its diameter increases while the diameter of the supply spool decreases. A speed control mechanism (G) controls the angular velocity of the take-up spool and accounts for the variation in spool diameter as the filter material reels off of the supply spool and onto the take-up spool. The speed control mechanism will keep the linear speed of the geotextile filter constant as it passes over the window of active filtration (D). In a similar fashion, a tension control mechanism (H) regulates the friction on the supply spool in order to keep the filter tensioned to a constant level. Constant strap tension must be maintained throughout the filtration process to ensure proper sealing at filter edges. A fluid level sensor monitors the wastewater level within the WFU and ensures that the system will not overflow. It was envisioned that the filter would be attached to the take-up roll by simply fixing the filter's strap drive attachment holes over hooks on the take up spool (Figure 3-8). When a roll of geotextile filter is expended, a new roll will be manually moved into place and the beginning of the new roll will be attached to the end of the used roll. This feature allows easy and clean installation and threading of the filter in the guide channels without the need to ever empty the filtration tub. Once the new roll is threaded through the channel guides (B) it is detached from the dirty roll and then attached to a new take-up spool using the strap drive attachment holes (Figure 3-8).

In Figure 3-7, a catch basin (I) beneath the curved stainless steel (E) tub collects the filtered wastewater so that it may then be pumped away for further processing. Solid waste trapped on the geotextile filter will be rolled up onto the take-up spool (C) and incinerated with the rolled fabric.

3.3.2.1 Analysis of Filter Performance Parameters.

The next step is the analysis of the relationship between the size of the active filtration window and other process parameters. Figure 3-9 depicts an active filtration window, having the dimensions of width *w* and length *l* under a length of fabric. This analysis was based upon the filtration properties of a particular type of geotextile material, the dimensions of the window, the velocity of the continuous filter over the open flow window, and other process parameters. This section demonstratesa methodology that can be used to develop WFU design parameters.

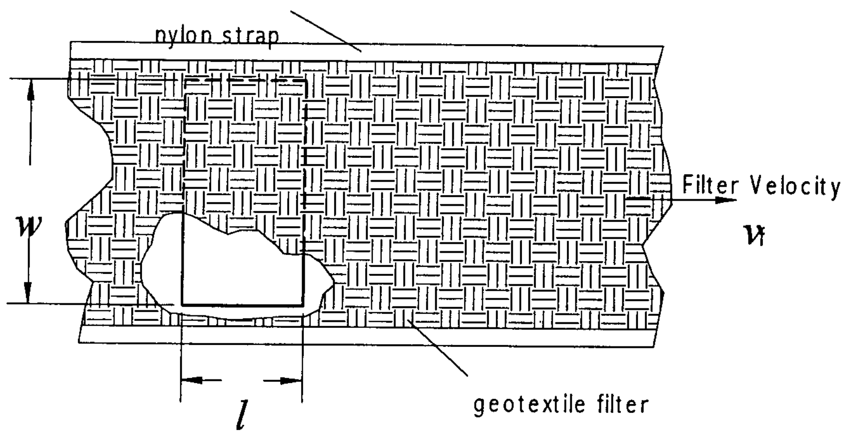

Figure 3-9. WFU filter and Window of Active Filtration.

Common to all materials tested for their filtration performance was the initial high flow rate that gradually reduced to a low rate after the first five to ten minutes of flow. In order to demonstrate the fundamental relationships that control the filtration process, the set of test results performed on a sample of LINQ geotextile filter material were selected. The results of the flow test for this material are shown inFigure 3-10.

While performance of just one type of filter is used here, the methodology employed can be used for any other filter data or for averaged filter performance data.

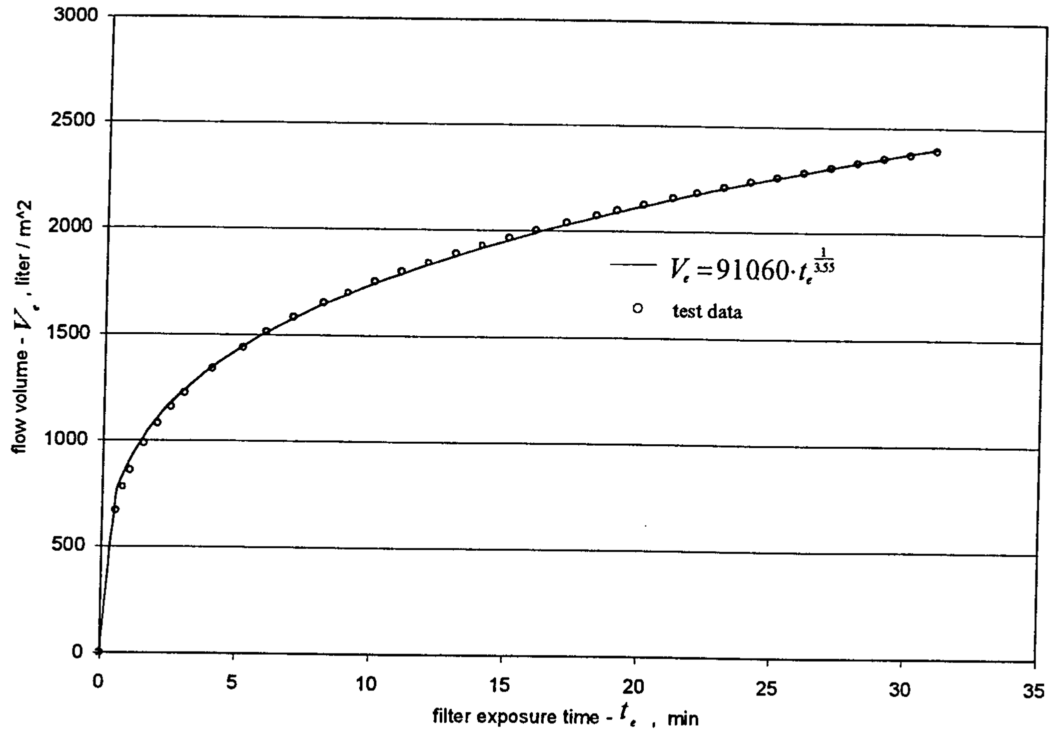

Figure 3-10. Flow Volume versus Filter Exposure Time for a LINQ Fabric under 0.6m head.

The filter exposure time t_e is defined as the time that it takes an area element ΔA of the moving filter to pass over the flow window, and the flow volume V_e as the volume of fluid that passes through one square meter of filter material during the exposure time t_e. Applying a Least Squares curve fitting technique to the test data of Figure 3-10, provides a mathematical relationship between the two related parameters, filter exposure time t_e and the flow volume per square meter V_e. A power function of the form

$$V_e = a \cdot t_e^{1/n} \qquad (3)$$

was selected to serve as a best fit mathematical expression for the test data. The Least Squares approximation determined that a=910.60 and n=3.55. The solid line in Figure 3-10 illustrates this power function, revealing good agreement with the test data set. Equation 3 then represents the filter characteristics and may be used in the computation of filtration process parameters. While the analysis of section 3.2 used a logarithmic function, the exponential form was used in this section for convenience. As previously mentioned, we are demonstrating a methodology here which can be used in the analysis of performance data for any filter.

Calculations of filter performance based on two different scenarios were generated. The first represents a filtration unit serving an individual Force Provider latrine and the second a filtration unit serving the combined blackwater and graywater flow from a Force Provider bladder.

The latrines in a Force Provider have a single 1,330 liter (350 gallon) holding tank which is defined as V_{tank}. Each latrine holding tank will be filled completely twice a day. Dividing the day into two equal shifts of 12 hours each, an average tank fill rate (tfr) is defined as:

$$tfr = \left[\frac{1330 \ \ liters}{12 \cdot hr}\right]\left[\frac{1 \cdot hr}{60 \cdot min}\right] = 1.8 \cdot liter/min \qquad (4)$$

For purposes of the analysis, two 12-hour periods each day during which the wastewater would be collected and processed were established. This restriction dictates that filtration processing be completed during each 12 hour period. Defining p as the fraction of the holding tank that is filled when the filtration process begins, the process time must not exceed the limit of

$$t_{process} \leq 12 \cdot hr\left[\frac{60 \cdot min}{1 \cdot hr}\right] \cdot (1-p) = 720 \cdot (1-p) \qquad (5)$$

minutes. When processing of the holding tank fluid begins, production of wastewater was assumed to remain at a constant rate tfr. Incorporating the constant tank emptying rate (ter) parameter in the following flow balance equation, an expression for ter is obtained

$$tfr \cdot t_{process} + p \cdot V_{tank} = ter \cdot t_{process} \qquad (6)$$

Equation (6) is then resolved to obtain an expression for the tank emptying rate ter

$$ter = tfr + \frac{p \cdot V_{tank}}{t_{process}} \qquad (7)$$

The level of fluid in the tub was set to remain constant during the filtration process. This requirement enables the WFU process balance equation

$$ter \cdot t_e = V_e \cdot w \cdot l \qquad (8)$$

where ter is the latrine holding tank emptying rate, t_e is the filter exposure time, V_e is the volume of fluid that passes through one square meter of filter material during the exposure time t_e, w is the width of the active flow window, and l is the length of the active window parallel to the direction of the filter motion. The left side of equation (8) represents the WFU inflow from the latrine holding tank during a time interval of t_e minutes, while the right side is the outflow from the active flow window. Substituting equations (3) and (7) into equation (8), process time $t_{process}$ may be expressed as a function of the filter exposure time t_e

$$t_{process} = \frac{p \cdot V_{tank}}{a \cdot t_e^{(1/n)-1} \cdot w \cdot l - tfr} \qquad (9)$$

Equation (9) serves as an analytical tool to study behavior of system parameters. For example, it should provide the means to decide when during a 12 hour shift to begin the filtration process by examining the result of varying the holding tank fill fraction number p. It also provide insight on the selection of the filter exposure time t_e, and on the selection of the tub active flow window dimensions w and l. The selected window length l plays an important role in the design since selection of l dictates the velocity at which the geotextile filter moves over the WFU active window. Given the selected window length l, the filter velocity v_f is expressed as

$$v_f = \frac{l}{t_e} \qquad (10)$$

Moreover, the overall geotextile filter length L_f used during one filtration cycle, is determined by

$$L_f = v_f \cdot t_{process} \qquad (11)$$

Using the analytical method described above, a set of process simulation calculations were made to demonstrate the ability to evaluate, display, and select the design and operating parameters of the filtration process.

In order to demonstrate a typical parameter evaluation process, we set the holding tank fill fraction coefficient at p=0.95. This limits the filtration processing time in equation (5) to $t_{process}$ less than or equal to 36 minutes. WFU tub active flow window width and length were selected to be w=0.5 m and l=0.3 m, respectively. A uniform filter exposure time range of 0 to 31 minutes was selected, similar to the test data range in Figure 3-10. Using these parameters, the following system characteristics were computed and are displayed in Figure 3-11 through Figure 3-15, respectively:

Figure 3-11. Filtration Process Time versus Filter Exposure Time
Figure 3-12. Filter Velocity versus Filter Exposure Time
Figure 3-13. Filter Length per filtration cycle versus Filter Exposure Time
Figure 3-14. Filter velocity versus Process Time, and
Figure 3-15. Tank Emptying Rate versus Process Time

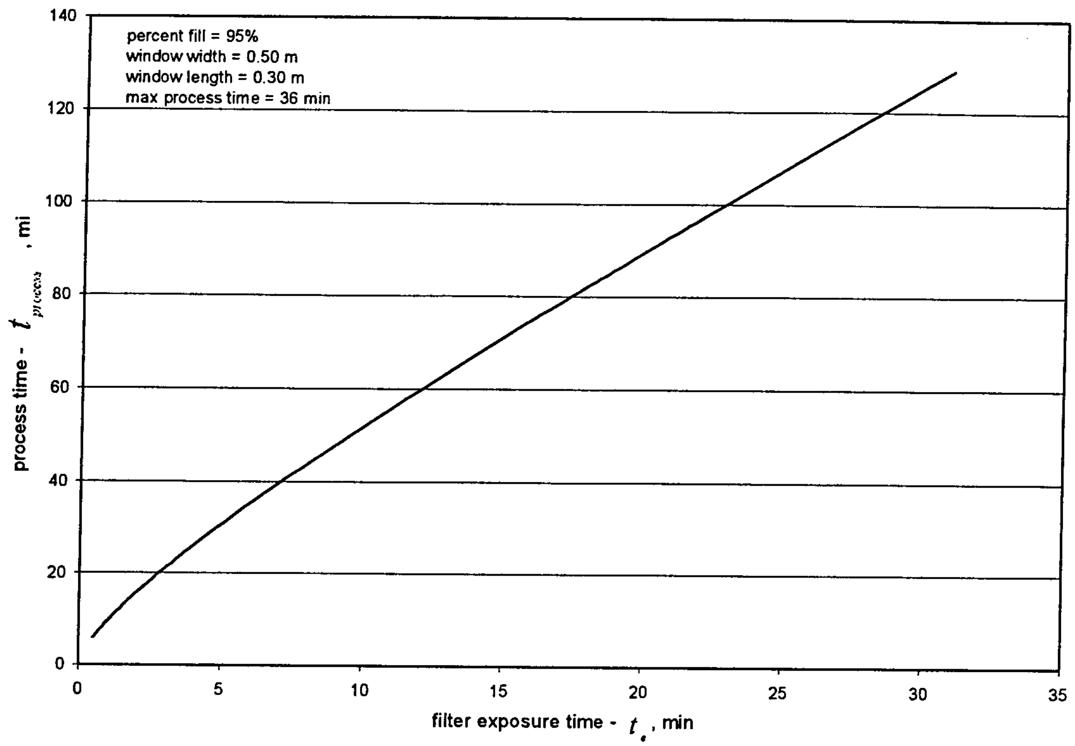

Figure 3-11. Process Time versus Filter Exposure Time.

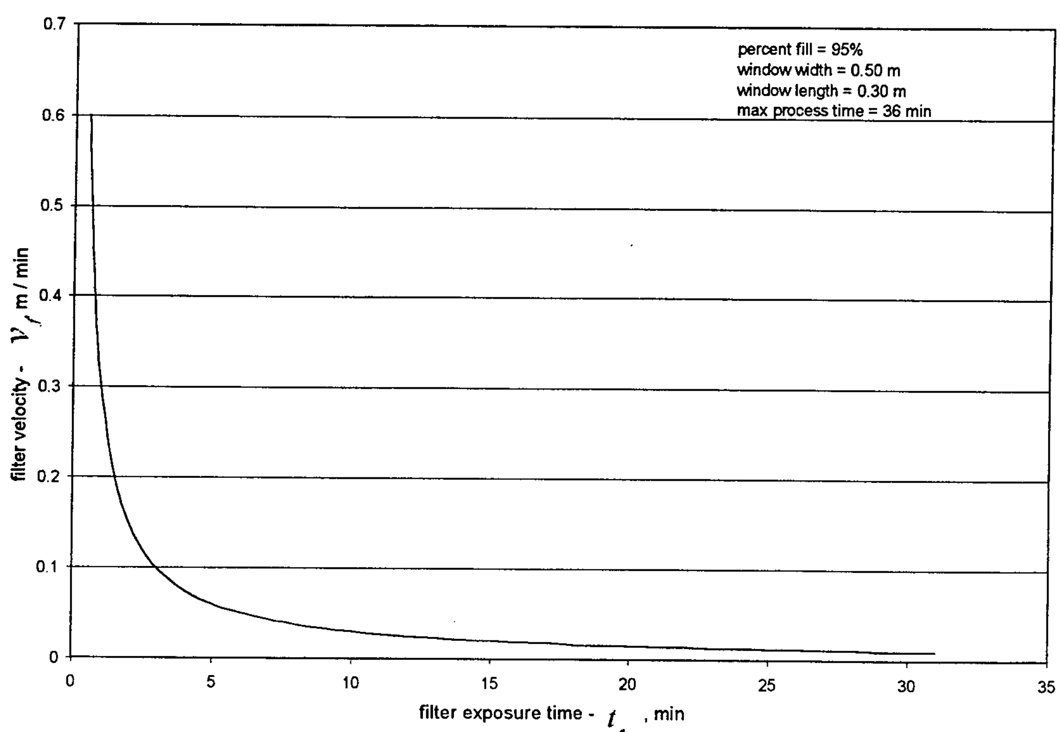

Figure 3-12. Filter Velocity as a Function of Filter Exposure Time.

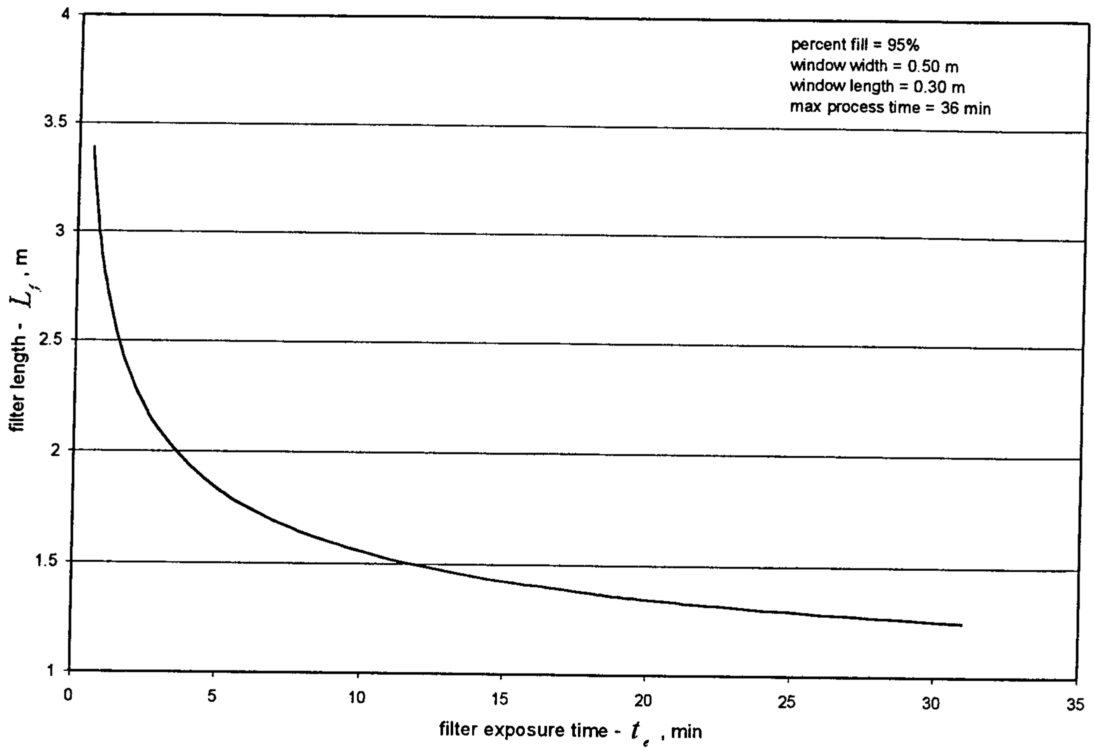

Figure 3-13. Filter Length versus Filter Exposure Time.

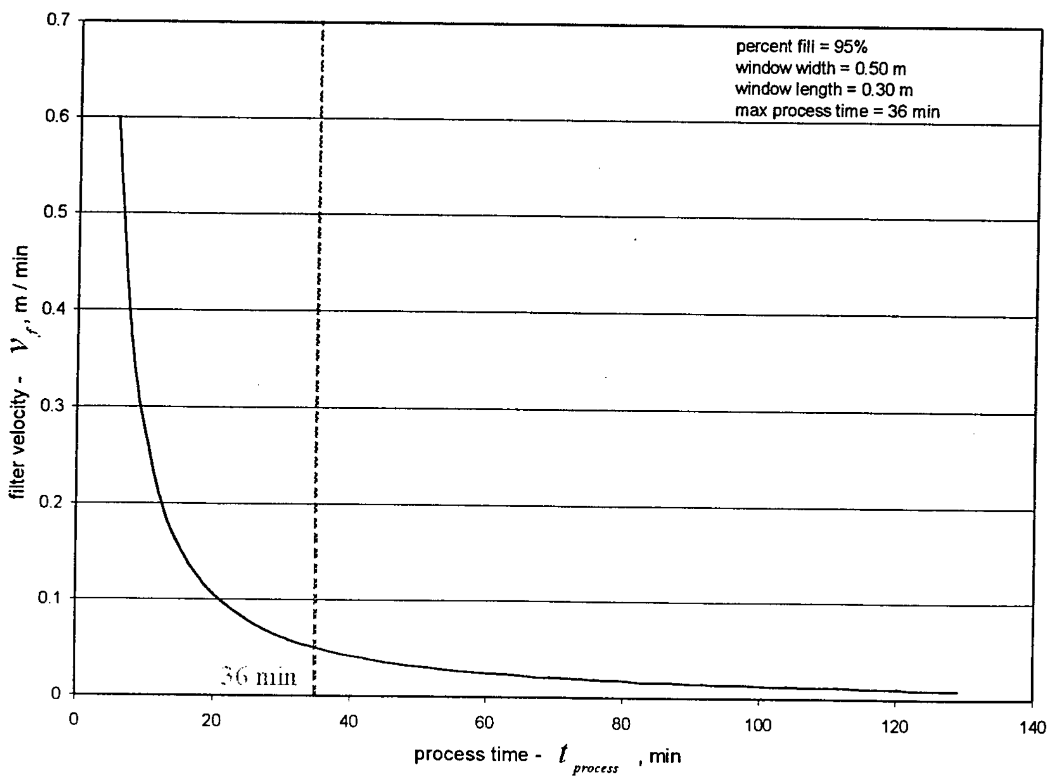

Figure 3-14. Filter Velocity as a Function of Process Time.

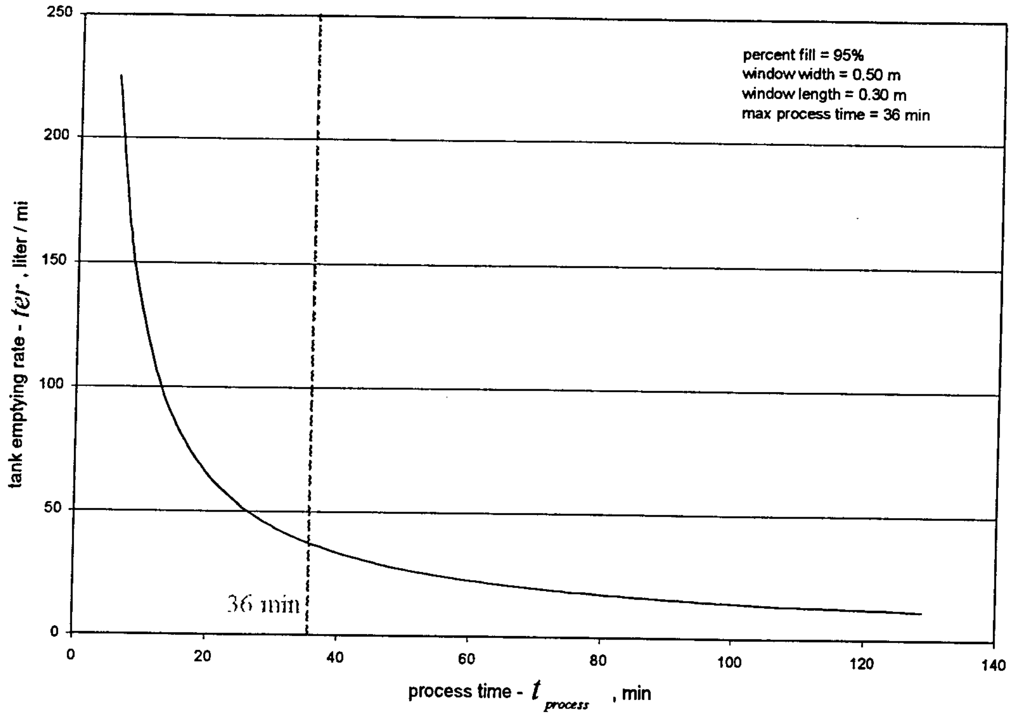

Figure 3-15. Tank Emptying Rate as a Function of Process Time.

In order to minimize the size and required capacity of the filtration equipment, the time available to process the wastewater, filtration-processing time, must be maximized. Using the maximum allowable cycle processing time in this example of 36 minutes, related design parameters for active flow window lengths of 0.3, 0.2, and 0.1 meter were calculated. Table 3-5 provides a summary of the data.

Tub window length l (m)	Filter exposure time, t_e (min)	Filtration process time $t_{process}$ (min)	Filter velocity v_f (m/min)	Filter total length L_f (m)	Tank emptying rate, ter (liter/min)
0.3	6.21	36	0.05	1.74	37
0.2	3.54	36	0.06	2.05	37
0.1	1.35	36	0.08	2.69	37

Table 3-5. Summary of Related Design Parameters.

The preceding paragraphs describe the analytical method for studying a WFU processing a small waste generator. An analysis for the case where the WFU must process a large 76,000 liter wastewater bladder was also conducted. For this case, it was assumed that a single bladder has the capacity to collect all sources of wastewater over a period of 24 hours before it becomes full. When the bladder reaches its maximum fill volume, wastewater is then directed to a second bladder while the first bladder empties to the WFU for processing. Under these conditions and using the same assumptions as the analysis for the WFU processing a single latrine, an average bladder fill rate (*bfr*) is defined as

$$bfr = \left[\frac{76000 \cdot liters}{24 \cdot hr}\right]\left[\frac{1 \cdot hr}{60 \cdot min}\right] = 52.8 \cdot liter/min \qquad (12)$$

In this case, it was assumed that 24 hours were available to complete processing which sets an upper limit on the filtration process time. Defining q as the fraction of the day to complete filtration, the process time becomes

$$t_{process} = 24 \cdot hr\left[\frac{60 \cdot min}{1 \cdot hr}\right] \cdot q = 1440 \cdot q \qquad (13)$$

minutes. Since the bladder is full when the filtration process begins, the process parameters examined are independent of the bladder fill rate *bfr*. Eliminating the bladder fill rate *bfr* from the template of equation (6) and setting the bladder fill fraction when filtration process begins to p=1, bladder emptying rate (*ber*) is obtained from the following flow balance equation

$$V_{bladder} = ber \cdot t_{process} \qquad (14)$$

Equation (14) can be resolved to obtain an expression for the bladder emptying rate *ber*

$$ber = \frac{V_{bladder}}{t_{process}} \qquad (15)$$

As previously assumed, during the filtration process, the level of fluid in the tub will remain constant. Therefore, the process balance equation is

$$ber \cdot t_e = V_e \cdot w \cdot l \qquad (16)$$

where *ber* is the bladder emptying rate, t_e is the filter exposure time, V_e is the volume of fluid that passes through a one square meter of filter material during the exposure time t_e, w is the width of the active flow window, and l is the length of the active flow window parallel to the direction of the filter motion. Substituting equations (3) and (15) into equation (16), process time $t_{process}$ may be expressed as a function of the filter exposure time t_e

$$t_{process} = \frac{V_{bladder}}{a \cdot t_e^{(1/n)-1} \cdot w \cdot l} \qquad (17)$$

Equation (17) is similar to equation (9) with the elimination of bladder fill rate parameter *bfr* and the setting of the bladder fill fraction to p=1. Given the selected active window length l, the filter velocity v_f may be obtained from equation (10). Equation (11) may be used again to determine the overall geotextile filter length L_f, used during the bladder filtration cycle.

As before, process simulation calculations were made to examine the operating parameters as a function of some process assumptions. In order to demonstrate a typical parameter evaluation process, q (the desired fraction of the day for processing) was selected to be 0.54 to reflect a daily process time of about 13 hours. The 13 hour process time was selected because it is roughly the time required to process the full volume of liquid waste (76,000 liters) at half of the experimentally determined hydraulic capacity (2,000 liters per square meter in 10 minutes of exposure or 200 liters/min). Half of the estimated value of hydraulic capacity was used just to be conservative.

An active flow window width of w=0.5 m was arbitrarily selected, and several window lengths of l=0.5, 0.4 and 0.3 m, were evaluated. Based upon the selected parameters with processing time of 780 minutes, system characteristics were determined. Table 3-6 provides a summary of related system characteristics for the assumed active flow window lengths.

Tub window length l (m)	Filter exposure time, t_e (min)	Filtration process time $t_{process}$ (min)	Filter velocity v_f (m/min)	Filter total length L_f (m)	Bladder emptying rate, ber (liter/min)
0.5	3.3	780	0.16	120	97
0.4	2.4	780	0.17	130	97
0.3	1.6	780	0.19	146	97

Table 3-6. Summary of Related Design Parameters.

Plots for the system characteristics were not generated in this case since they would be analogous in appearance to the plots obtained for the case of the WFU servicing an individual latrine.

The methods and process simulation results discussed above show that it is feasible to develop a WFU that can handle the range of wastewater capacities that might be required at a Force Provider module. The analytical techniques developed provides insight into the filtration technique and operating parameter evaluation. The simulation calculations predicted a range of parameters and dimensions that appear acceptable for the Force Provider module. As with any modeling and simulation study, real time laboratory testing is needed so as to validate simulation results and to reduce calculation errors.

3.4 INCINERATION SUBSYSTEM STUDIES.

3.4.1 Major Findings.

- Batch processing of wastes appears to be more practical than continuous feed.
- There are commercially available incinerators, including one presently being used by the British in Kosovo, which can be adapted to meet the Force Provider requirements.

3.4.2 Discussion

Two (2) incinerator concepts were examined under this study – the INCINOMAT and the Crawford CB26SW-UKMOD. Although the INCINOMAT was determined to have insufficient capacity, it is extensively discussed to provide insight into the design characteristics considered. The Crawford incinerator is a candidate to be considered for the waste treatment system.

To design an incinerator, the relationship between process parameters must be developed. Based on known chemical formulae for organic waste and polypropylene, the heats of reaction were calculated and compared it to the heats of formation of products to prove that the combustion of waste-contaminated polypropylene would be self-sustaining. Subsequent conversations with incinerator manufacturers confirmed these calculations. An estimate was developed for the ignition temperature of the fabric/waste/water mixture and how much auxiliary fuel was required to elevate the mixture to that temperature. Stoichiometric relationships were developed for complete combustion of the fabric/waste constituents and the amount of required combustion air was estimated. A method for computing the steady-state combustion temperature was established and the flue gas byproducts and the time/temperature requirements to avoid producing exhaust contaminants were discussed.

Using the theoretical considerations mentioned above, the initial concept was to design the WFU with an integral incinerator that would accept the continuous feed of used geotextile fabric. When it was learned how little fabric would be generated on a daily basis, it was felt that batch processing would be more cost effective and that using one or more centralized incinerators would be the most effective use of burn time. Safety was also a concern of the continuous process in that the fabric in a continuous feed arrangement would act like a wick and allow burning outside the combustion chamber. It also became apparent that the incinerator design process for the fuel nozzle, fuel-air mixing device, refractory, combustion air flow modeling, and combustion chamber sizing would require a level of effort that was not intended for this study. Therefore, it was thought to be more practical to use an off-the-shelf incinerator integrated into the system rather than designing an incinerator from scratch. Incinerators that could be used as is or modified to suit this application were researched based on the parameters that had been generated.

Of all the incinerators studied, two stood out as worthy of discussion here because they represent the extremes in terms of size and capability. The INCINOMAT[28] is at the small end of the spectrum and the Crawford[29] CB26SW-UKMOD is at the large end.

The INCINOMAT, which is shown in Figures 3-16 and 3-17, is an electric incinerator designed for use in the home or office. It weighs 82 kilograms (180 pounds) and is about the size of a home clothes dryer: 86.5 cm wide, 71 cm deep, and 91.5 cm high. It is designed to burn two to three pounds of paper per hour or a mixture of one pound of wet garbage per pound of dry paper per hour. It is smokeless, generates no odor, and has surfaces that get hot but won't burn if touched. It uses standard 120-volt power at the rate of 1600 watts during a 40 minute start up period and 200 watts thereafter. It retains combustion products at 1093 degrees Centigrade (2,000 degrees Fahrenheit) long enough to destroy toxic byproducts.

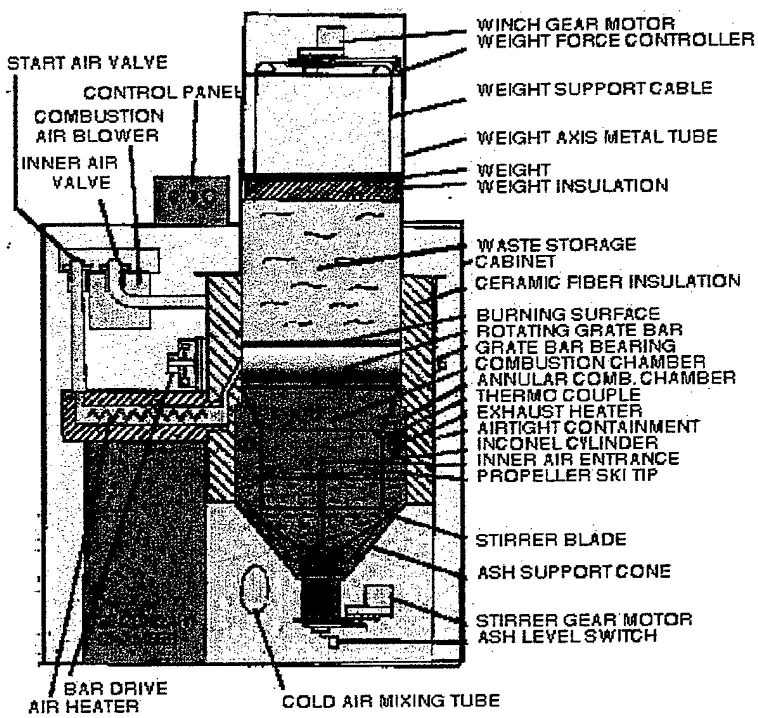

Figure 3-16. Front View of the INCINOMAT.

28 Manufacturer is the Franklin Control Company, Box 61 Post International Suite 572, New York, NY, Telephone 888-837-9617.

29 Crawford Equipment and Engineering Co, 436 W Landstreet Rd, Orlando, FL, Telephone 407-851-0993.

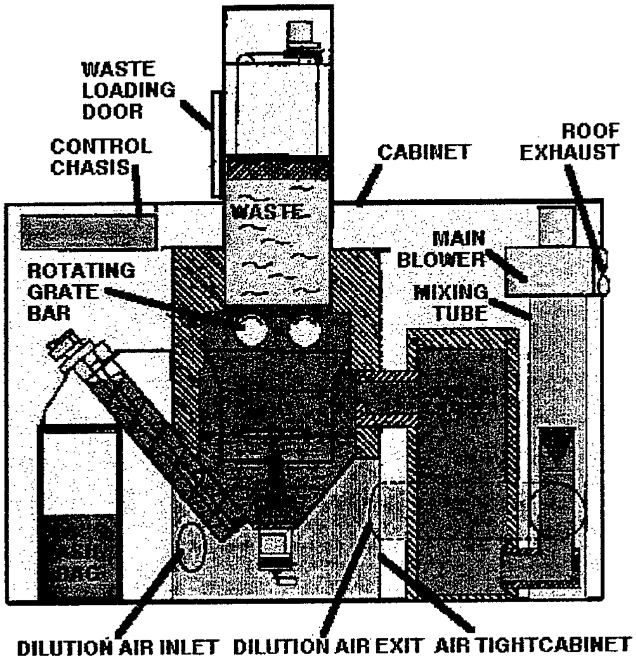

Figure 3-17. Side View of the INCINOMAT.

The INCINOMAT is designed to operate in a batch feed mode – the waste loading turret has a one bushel capacity which must completely burn before the next load can be started. In the current design, complete burning of a load can take up to 8 hours depending on the nature of the material being burned. Burning a load every three days will produce about a grocery bag full of ash in one month.

The waste-loading turret of the INCINOMAT can accommodate about 5 kg (11 pounds) of geotextile fabric if the fabric could be shaped to fill the entire chamber. That would equate to a daily burn rate of 15 kg (33 pounds) assuming three burn cycles per day. For this application, processing about 76,000 liters per day in both primary and secondary filtration units, should collect about 80 kg (176 pounds) of fabric per day, including the entrained waste. These figures are based on potential system characteristics discussed in Section 4.2. Use of six INCINOMATs, as they are currently configured and rated, would be required just to process waste. Others would need to be available for redundancy and spares. A significant obstacle to overcome would be how to alter the fabric to get the maximum amount of it into the limited space of the loading turret or how to modify the turret to accept the largest amount of fabric per burn cycle.

In conversation with the manufacturer, it was learned that they could modify the INCINOMAT to accommodate the designed waste stream. INCINOMAT feels their unit can handle the mixture of polypropylene fabric, filtered organic waste, and the entrained water. The manufacturer estimated a $5,000 per unit cost which could be reduced to about $2,000 per unit if purchased in quantity.

The Crawford Equipment and Engineering Company makes, among others, the CB26SW-UKMOD incinerator. It was learned that the British Ministry of Defense recently purchased 27 incinerators of various capacities from Crawford for use in some of the 16 field camps in Kosovo. These incinerators which included the CB26SW-UKMOD were all modified to fit ISO containers.

The CB26SW-UKMOD has a 90 kilogram (200 pound) batch-load capacity with a 4 to 6 hour batch cycle-time. Assuming just three batches a day, it can process 270 kilograms (600 pounds) per day. As mentioned above, the system will generate about 80 kg (176 pounds) of fabric per day. The incinerator will be able to batch process all of the WFU solid waste in one burn cycle each day, leaving 66 % of the incinerator capacity free for combustion of other solid waste in the Force Provider. While the CB26SW –UKMOD might appear to be oversized for the Force Provider application, it was decided to include it in this discussion because it has already been adapted for use in an ISO container and it is being currently used in temporary military camps overseas.

These incinerators can use diesel fuel as an auxiliary source of fuel if needed and they have a baffled secondary combustion chamber to provide the temperature and residence time needed to meet environmental requirements. A schematic of the CB26SW-UKMOD inside an ISO container is shown in Figure 3-18.

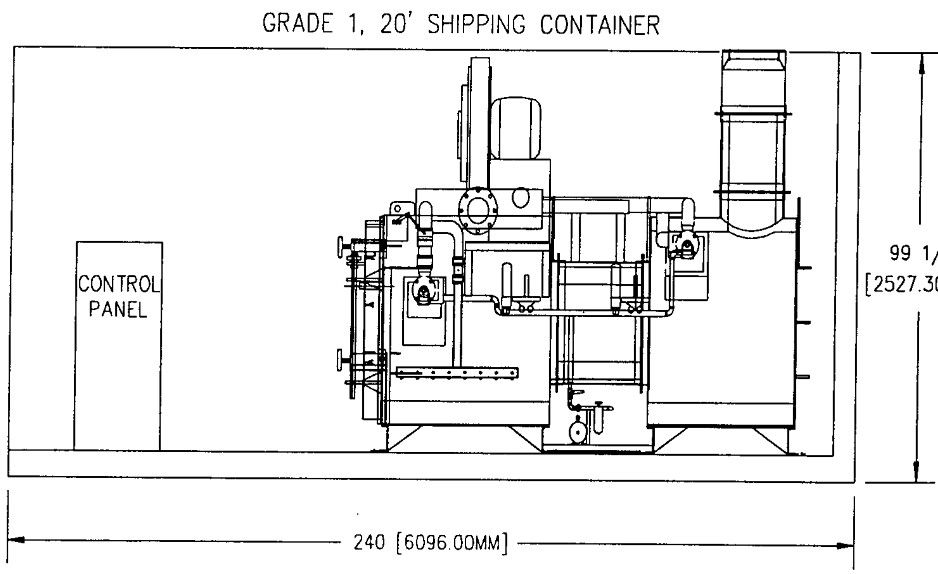

Figure 3-18. Schematic of the Crawford CB26SW-UKMOD in its Integral ISO Container.

The CB26SW-UKMOD weighs 4,717 kg (10,400 pounds) including the ISO container that houses the control and supporting systems. As the name indicates, the CB26SW-UKMOD is a modified version of a standard Crawford incinerator. The modifications include a fuel system that burns diesel fuel vice natural gas, repositioning the primary and secondary combustion chambers to fit in the container, changing the motors to run on 50 cycle power, and modifying the stack to induce a greater draft. The cost of the containerized CB26SW-UKMOD incinerator is $33,520. (The unmodified CB26SW costs $24,411.) The cost of the Crawford unit would appear to be justifiable only if the excess capacity of the incinerator could be put to good use in a Force Provider Camp.

3.5 SECONDARY TREATMENT SUBSYSTEM.

3.5.1 Major Findings.

- A Moving Bed Biofilm Reactor (MBBR) process appears to be one of the most feasible processes available to meet Force Provider liquid waste stream requirements.

3.5.2 Discussion.

A cursory survey was conducted to find out what secondary biological treatment systems were available from industry that would meet the same Force Provider constraints (size, weight, and power) as the filtration and incineration subsystems.

The smallest biological secondary treatment system found after a cursory survey was the BIOSORB Digester Module.[30] The BIOSORB uses air injected over internal media to enhance biological growth on the media and consume organic waste in the process. It has a flow capacity of 3,785 liters/day (1,000 gallons/day) but it will only treat a BOD load of 2.5 pounds (1.1 kg) per day. Two of these secondary treatment modules that weigh 1,050 pounds (476 kg) each could easily fit into a single ISO container. The flow capacity of the module can easily accommodate the flow from a single Force Provider latrine. However the blackwater BOD load at 1,400 mg/l (assuming a 50% BOD reduction in the primary filtration unit) is roughly five times higher than the BIOSORB module capacity (300 mg/l at 3,785 l/day). A schematic of the BIOSORB module is shown in Figure 3-19.

30 Manufactured by RGF Environmental Group, 3875 Fiscal Court, West Palm Beach Florida, 33404, Telephone 800-842-7771.

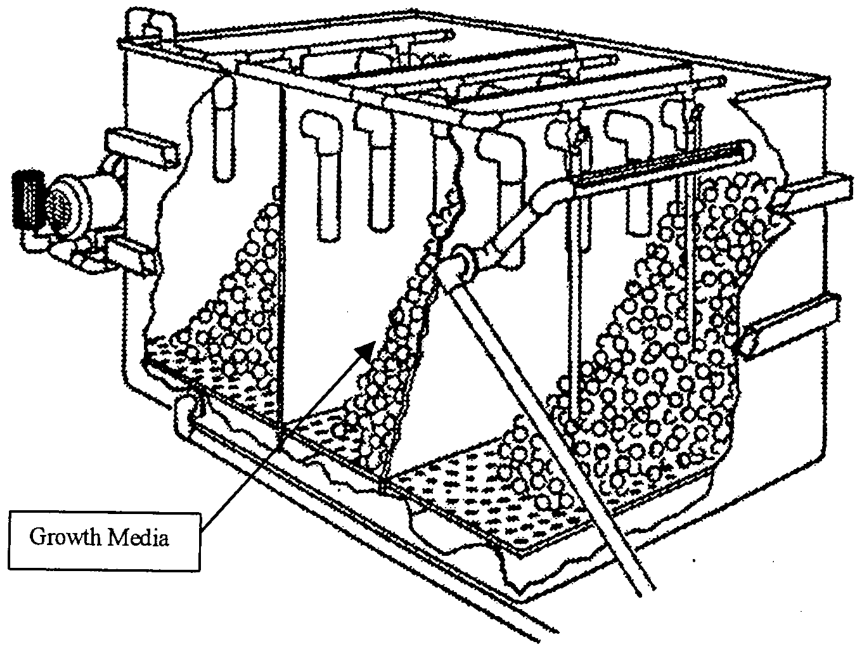

Figure 3-19. A Schematic of the RGF BIOSORB Secondary Treatment Module.

It was concluded that for the high BOD load from the Force Provider latrines a "typical" secondary treatment unit could probably not be found. This conclusion suggested that a secondary treatment has to occur with a more dilute wastestream or with a combined blackwater and graywater wastestream.

The Moving Bed Biofilm Reactor (MBBR) process was then examined.[31] In this system, both activated sludge and fixed-film processes occur in a bioreactor where the growth media are circulated in the wastewater by coarse bubble aeration. The net effect is higher than average waste removal in a small system. The growth media circulated inside the reactor are polyethylene wheels 7mm long and 10 mm in diameter. They are constructed to maximize surface area per unit volume so that biological growth area is optimized. One half to two thirds of the bioreactor volume can be filled with the growth media depending on the strength of the wastewater to be processed. A media fill of 67% will provide 333 m^2 of active biofilm surface area per cubic meter of water volume.

The MBBR distributor claims the process has been used in over 35 municipal treatment plants for more than ten years and that in excess of 110 of these plants are in operation worldwide.

31 Licensed for distribution in the US by WATERLINK, 630 Current Road. Fall River Massachusetts 02720, Telephone 508-679-6770.

It was learned that a MBBR system could be built for the Force Provider application and sized to meet the flow and BOD load of the combined blackwater and graywater waste streams. For a combined waste stream with a BOD load of 300 mg/l (assuming a 50% BOD reduction in the primary filtration unit) at a flow rate of about 76,000 l/day (20,000 gallons/day), the distributor estimated secondary clarification effluent to be 15 mg/l. While the Force Provider application would use WFUs vice conventional secondary clarification, it seems reasonable to expect similar performance.

For the flow and BOD load in this application, the distributor recommended one reactor tank with a 16.2 cubic meters (572 cubic foot) volume that would operate with a 35% fill of growth media or "carrier elements." The tank would require 85 SCFM air flow of course bubbles. The tank dimensions would be 2.7 m (9 feet) in diameter and 3.7 m (12 feet) high with a .9 m (3 foot) freeboard inside the tank. The tank dimensions would be bigger than the standard ISO container but negotiation with the manufacturer to customize the tank size is feasible. Two positive displacement blowers each rated at 85 SCFM at 5.4 psi were recommended for the application.

The cost for a single MBBR unit as described above and as shown in Figure 3-20, was estimated at $53,000.

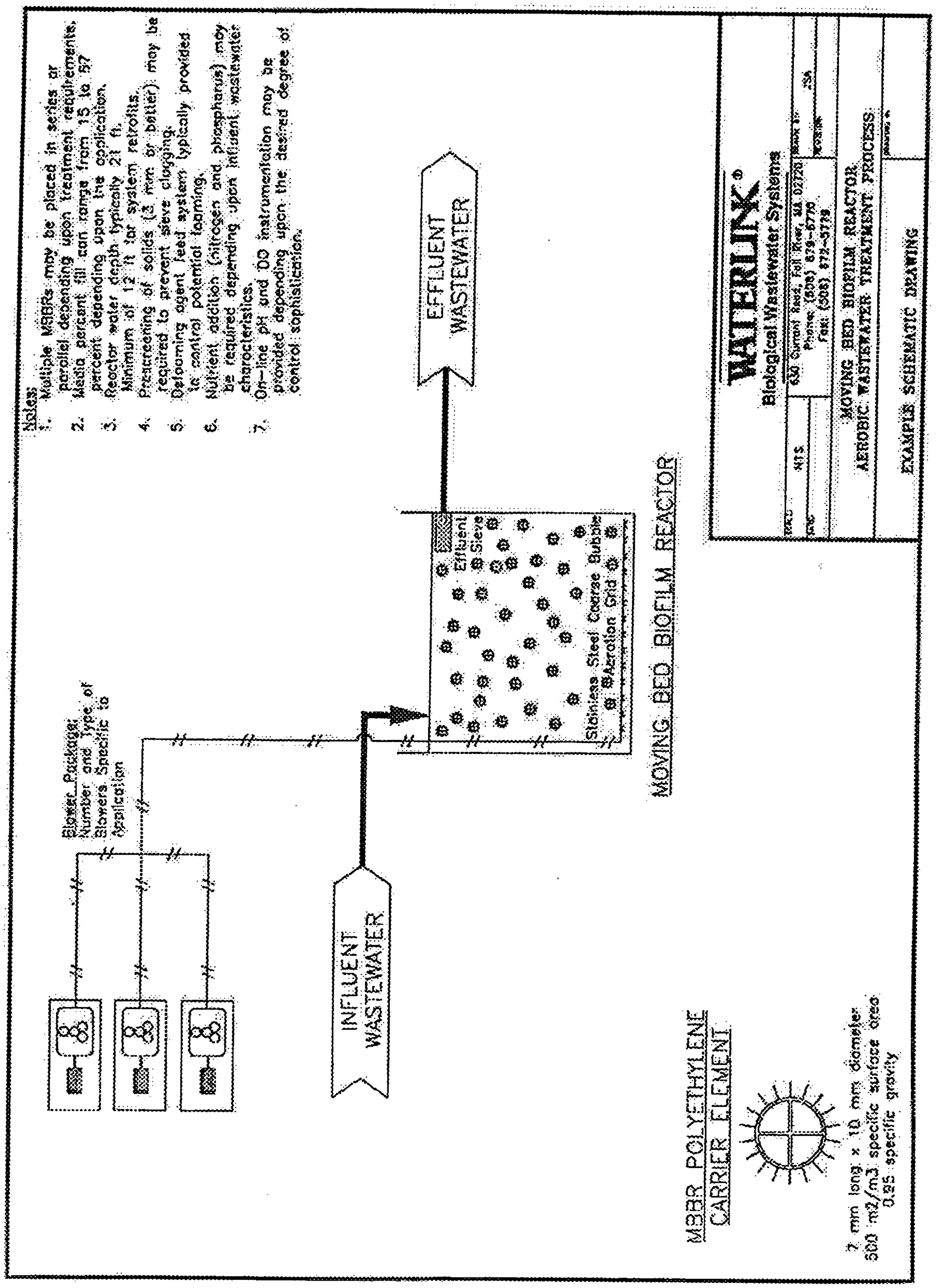

Figure 3-20. THE SCHEMATIC OF THE MOVING BED BIOFILM REACTOR (MBBR).

SECTION 4

DESIGN CONCEPT

4.1 OVERALL SYSTEM CONFIGURATION.

The UTD Inc. concept of the system configuration has evolved during the execution of this study. This section discusses how that evolution took place.

The original configuration, if test results confirmed estimated capacities, was to have small self-contained Wastewater Filtration Units (WFUs) at each source of wastewater. Using the Total Suspended Solids load listed in Figure 2-2 and the relationship for hydraulic capacity as a function of TSS developed by Martel[32], the amount of fabric required was estimated. A single filtration unit for each latrine would require about 48 square meters of fabric per day (TSS of 1500 mg/l, hydraulic capacity of 56 l/m^2, flow of 2,650 l/day). Each of two filtration units on a bladder would require about 94 square meters of fabric per day (TSS of 300 mg/l, total hydraulic capacity of 403 l/m^2, flow of 76,000 l/day). Based on these capacities and fabric usage rates, the configuration in Figure 4-1 seemed reasonable. The original concept was for each of these WFU units to have a primary filtration subsystem, a secondary subsystem, an incinerator subsystem, and a secondary filtration subsystem.

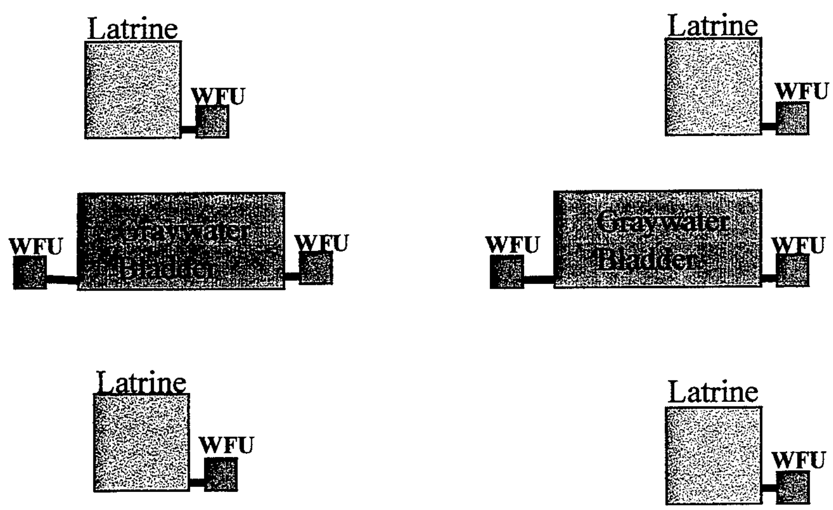

Figure 4-1. The Original Distributed Concept for WFUs at a Force Provider.

In addition to the reasonable capacities and fabric usage rates, it was thought best to have many small WFUs to provide for more flexibility and greater operability. This way, if one WFU were to fail or need to be taken off-line for maintenance, only a small portion of the total capability is lost. Whereas, with a configuration of a small number of larger, centralized WFUs there would be a significant loss of capability if the WFU had to be taken off-line for any reason.

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32 Martel, C. J., et al, *Initial Evaluation of Geotextiles for Wastewater Filtration at Temporary Base Camps*, 1999.

It was proposed to add a sufficient number of spare WFUs to the original configuration so that if one were lost, the spare(s) could be employed to maintain full capability near constantly. It was also planned to scale the WFUs to fit the application. Therefore, the same basic WFU design could be used and scaled up or down to match the flow rate of the application, either graywater or blackwater.

It also seemed reasonable to expect similar results regardless of the type of waste stream, either blackwater or graywater. To do so, it would be necessary to make adjustments in WFU fabric speed, and length of on-off cycles to accommodate the different TSS and BOD loads in the different wastewater streams.

The original concept evolved to that shown in Figure 4-2. Two factors spurred the evolution. First, ten times as much water could be processed as we originally thought possible. Second, it was considered more efficient to treat a combined waste stream that is homogeneous and has diluted blackwater TSS and BOD loads.

In the evolved concept, the latrines could still be pumped out as they are presently but the waste would be injected into one of the two bladders and combined with the graywater. Alternatively, the latrines could be hard-piped to the bladders and set to empty with a float switch. One or two WFUs would be on-line at any time to treat the combined stream and there would be a third WFU available in the event that one of the other two was lost. The TSS and BOD were calculated for the combined waste stream to be 447 mg/l and 616 mg/l respectively using the values of TSS and BOD in Table 2-2 and a proportional relationship for flow rates.

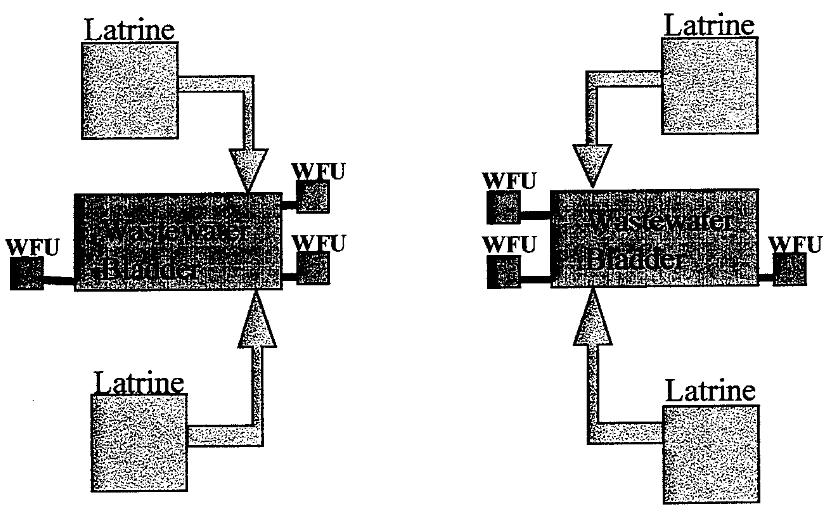

Figure 4-2. The Centralized WFU Configuration for Combined Waste Streams.

While this research project was intended to look at filtration and incineration alone, it became obvious that there would also have to be some preliminary thinking about the type and size of the possible secondary treatment subsystem that would be required to treat the waste stream. As discussed in section 3.5, off-the-shelf trickling filter units were located with advertised capacities that made them a good fit for the centralized concept since the treatment capacities of the units were far in excess of what could be generated by a WFU treating a single latrine. In addition, trickling filters operate best when the wastestream is as near constant as possible. The capacity and nature of the trickling filter units combined with the greater capacity of the filtration units pointed in the direction of centralized system that treats a combined wastestream.

It was recognized that the decision to keep the liquid waste streams separated or combined in a Force Provider camp is the prerogative of the Program Manager and may be driven by factors other than those discussed here. However, when the possibility of combining the liquid wastestreams with the Force Provider Program Manager's office was discussed, they indicated that it could be done if there were sufficient technical, operational, and economic benefit to do so.[33]

The initial plan was to develop a WFU with an integral incinerator to burn the used filter fabric and the entrained waste. Early studies showed that the fabric use rate was so low in a WFU attached to each latrine that a dedicated incinerator was not cost effective. Additionally, the complexities of incinerator and combustion design encouraged the use of an off-the-shelf incinerator unit that could be integrated with the other subsystems being developed. Commercially available incinerators were located that will burn from 1.5 kilograms (3 pounds) per hour up to 90 kilograms (195 pounds) per cycle of dry or nearly dry solids. These same incinerators will also fit into standard ISO containers and meet the container weight limitations.

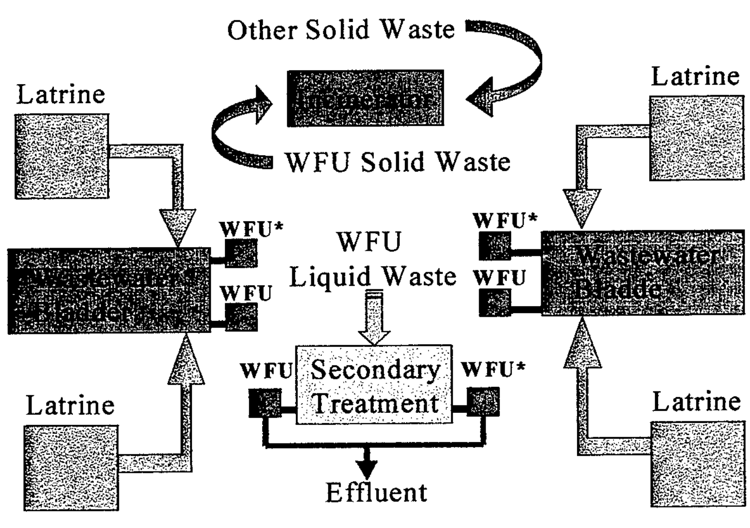

Figure 4-3. A Complete Centralized Treatment Unit.

*optional back-up units

33. Telephone conversation with Mr. Mike Gallagher, Force Provider Program Manager's Office, of October 25, 1999.

The research with incinerators also seemed to support the centralized concept as the best approach to take for the entire WFU system. In fact, the design and capacity of the Crawford incinerator suggests using the incinerator for both solid and liquid waste streams in a Force Provider camp. The optimum centralized concept would look similar to Figure 4-3.

4.2 SUBSYSTEM CONFIGURATION.

To match the overall system configuration pictured in Figure 4-3, a notional set of subsystem characteristics were developed that are described in the following paragraphs. What is described here is not a unique solution. There are other possible combinations of equipment sizes, capabilities, dimensions, and features. What is provided below is just one example of what the detailed description of a complete system could look like. The process flow diagram depicted in Figure 4-4 illustrates how the system works.

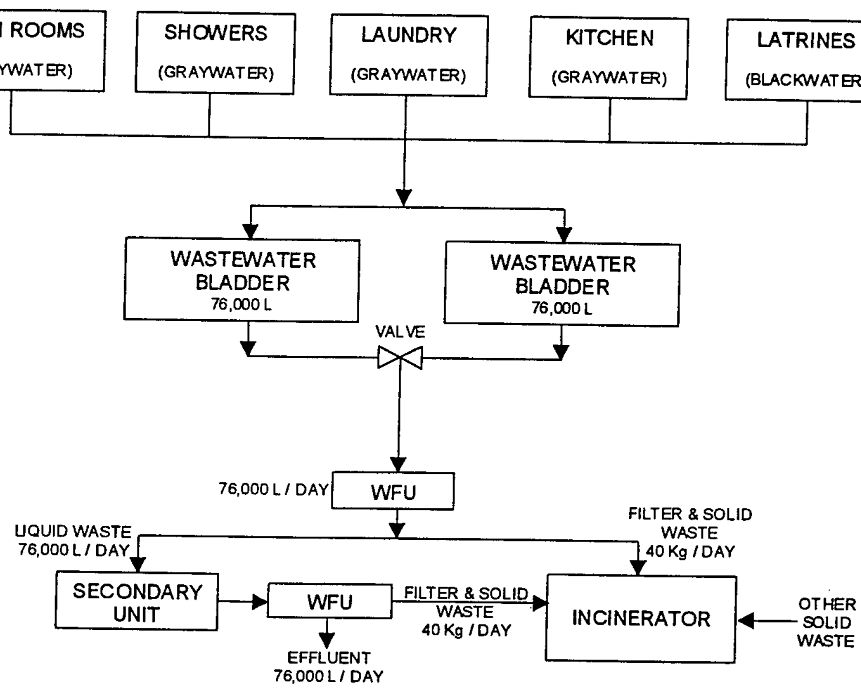

Figure 4-4. Process Flow Diagram of Waste Treatment Facility

Bladders:

Two 76,000 liter bladders would be available. They could be together or separated in the camp. At any time, one would be receiving the combined blackwater and graywater waste stream. The other bladder would be either emptying or empty and ready for the next filling cycle. When a bladder reached the full point, it would be taken off line and the liquid wastestream would be diverted to the other bladder. A pump, probably with a recessed impeller to grind up large solids, would be energized to move the waste in the full bladder to a WFU. Based on the example process calculations described in section 3.3, the bladder emptying rate would be about 100 liters per minute. At that rate, the bladder would empty in just less than 13 hours. It is emphasized again that these performance parameters are from just one example of the analytical methodology. The methodology can be used with other filter materials and other system configurations.

Filtration Unit:

A total of eight WFUs would be available, six would be operational and two would be kept as spares. All of the units would be identical and could be interchanged. At any given time, two units would be online, one processing waste from the bladder and one processing the secondary treatment effluent. The WFU tub diameter would be about 1.2m (4 feet). The active window for filtration in the tub beneath the filter fabric would be .5m in length by .5m in width. The roll of geotextile fabric going through the tub would be about 120m long and .75m wide if Amoco 4506 is used. The clean fabric roll would weigh about 20kg (45lbs), it would move through the tub at a speed of about .2 m/min, and it would last for the complete processing cycle of waste in the 76,000 liter bladder, about 13 hours. The fabric exposure time or time spent by each segment of fabric over the filtration window would be about 3.3 minutes. When the filtration cycle is completed, the spent roll of fabric would be removed and put into the incinerator. The dirty roll of fabric would weigh about twice as much as the clean roll assuming a 300mg/liter or 70% TSS reduction from filtration. The filtration unit would be expected to remove about 70% TSS and 50% BOD. The effluent from the filtration unit would be routed to the secondary treatment equipment.

Secondary Treatment:

A single Moving Bed Biofilm Reactor (MBBR) would be used to accomplish activated sludge and fixed film treatment processes. The MBBR unit would be separate from the WFU but it could be collocated next the filters. The MBBR reactor(s) or tank(s) would be two-thirds filled with growth media (plastic disks) and have a total treatment volume of about 16 cubic meters to accommodate 76,000 liters per day. The reactor tank volume and media growth fill volume would be designated to match the selected process time for the bladder and WFU. Two positive displacement blowers each rated at 85 SCFM at 5.4 psi would be needed to provide the coarse-bubble aeration in the reactor tank when processing 76,000 liters per day. Blower capacity would have to be resized depending on the selected bladder/WFU process time. The manufacturer stated that about 120 to 180 mg/liter of solids will be generated in the MBBR and be combined with any influent TSS to make up the effluent TSS concentration requiring filtration. Because it is a stand-alone process, there is no requirement for return sludge from secondary clarification that is typical in conventional treatment plants. The MBBR unit would be operational each day for a period that corresponds to the selected bladder/WFU process time.

Secondary Filtration:

There would be two WFUs in place to process the effluent from secondary treatment, one on-line and one in standby. The WFU that processes effluent from the MBBR would be the same size and capacity as the primary treatment WFU that processed waste right out of the bladder. The fabric and fabric usage rates for secondary filtration will depend on the process time selected but these parameters should roughly correspond to those used in the primary WFU. The spent fabric rolls would be sent to the incinerator. The regulations and permit requirements at the plant location will dictate disposal of the effluent from the secondary filtration unit.

Incinerator:

The Crawford CB26SW-UKMOD has a 90 kilogram (200 pound) batch-load capacity with a 4 to 6 hour batch cycle-time. It should be possible to burn all of the spent fabric generated in one day of processing in one batch burn cycle. That would leave the incinerator free from 16 to 18 hours a day to be used for incineration of solid waste generated at the camp. The incinerator would require a minimal amount of diesel fuel to get the spent fabric to ignition temperature and the fabric should burn self-sustaining after that. The incinerator has two combustion chambers which ensures the exhaust gases stay at an elevated temperature long enough to remove all potentially harmful contaminants. This incinerator is manufactured with an integral ISO container.

4.3 MAINTENANCE & OPERATION

The man-hour requirements to operate and maintain the equipment discussed above is estimated to be minimal for the filtration units and secondary treatment unit but moderate for the incineration unit. Taken together, the time requirements are probably enough to warrant a single person being assigned full time to care for the entire system.

If the incinerator is run continuously to dispose of liquid as well as solid waste, then it in particular, will need a person to check it frequently for loading and proper operation of its automatic control sequence for each batch cycle. Aside from the electronic controls for the incinerator, the air blower would probably require the most attention which should not be anything more than quarterly inspection and lubrication, and weekly cleaning of sensors.

Operation of the WFUs should require minimal observation and maintenance. If a foreign object in the wastestream can be pumped from the bladder to the filtration unit, it should be small enough to be retained by the fabric and not jam or clog the unit. Movement of the fabric rolls from the filtration units to the incinerator should require no more than two people for just a short period of time each day.

The secondary treatment unit will run unattended except for the air blowers which will require attention similar to the incinerator blower. Operation of the secondary unit will be more sensitive to temperature than the other components because it relies on microorganisms to remove the organic waste. Appropriate enclosures should be available to keep the secondary unit at a reasonable temperature. The internal growth media may need to be replaced on a regular basis.

4.4 TRAINING

A one-week training package would probably be sufficient to provide an individual 0with enough information on the treatment equipment to enable them to properly operate and maintain it. It is not envisioned to be necessary to add a new Military Occupational Specialty (MOS) just for wastewater treatment equipment. Virtually any of the existing MOS engineering could be used to operate and maintain the wastewater equipment provided they had some additional training on the systems. An Additional Skills Identifier (ASI) for wastewater treatment should be established.

4.5 COST

As a means of judging the feasibility and effectiveness of developing the systems discussed in this report, a rough order of magnitude (ROM) cost estimate was prepared. The costs used in this estimate are very rough and could vary by as much as an order of magnitude once consumables and equipment construction costs are better defined.

The costs for the secondary treatment unit and the incinerator were discussed in Section 3. The cost for the WFU filtration unit is largely based on labor costs at a typical machine shop that has the equipment and the technical capability to build the WFU as currently envisioned. The main body of the unit and most of the other structural elements are assumed to be made of 304 stainless steel or equivalent. Table 4-1 below summarizes the cost estimate for a single WFU.

Equipment	Unit Price
Tub container assembly – frame and walls	8,000
Tub container cover – frame and walls	4,000
Spool assembly of new geotextile filter	3,000
Geotextile constant tension mechanism	1,500
Spool assembly of used geotextile filter	4,000
Geotextile constant speed control mechanism	2,000
Sensor, water level	300
Influent pump	800
Fasteners, lot	400
Hoses pipes and accessories	300
Electrical connectors and accessories	800
Special machining operations	2,000
Miscellaneous	2,000
TOTAL COST	$29,100

Table 4-1. Itemized Cost for the WFU. A reduction of about 25% could be expected for quantities of five units and more.

For capital costs for the entire system, it was assumed:

- Six WFU units are identified with a life cycle of five years, with the per-unit-cost estimated at about $25,000 each.

- For the secondary treatment subsystem, a single Moving Bed Biofilm Reactor (MBBR) would be needed with a life cycle estimated at ten years and unit cost of $53,000.

- A single incinerator like the Crawford CB26SW-UKMOD would be replaced every five years at a cost of $33,000. Using 33 percent of the incinerator capacity for disposing of WFU solid waste. It was assumed that the remaining incinerator capacity could be used for disposal of other solid waste at the Force Provider. The capital cost due for wastewater treatment would, therefore, be $11,000.

<u>For operating and maintenance costs for the entire system, it was assumed:</u>

- The WFUs would consume a total of 180 square meters of fabric per day. This figure assumes the average fabric use is 90 square meters (120m long x .75m wide) per day and that an average of two WFUs are on-line for a full filtration cycle each day. Fabric costs are assumed to be about $2 per square meter. This cost is based on doubling the normal average price of $1 per square meter of fabric to cover the addition of nylon straps to the fabric edges. The miscellaneous parts would require another $500 per year. Total O&M costs are estimated at $131,900 per year.

- The secondary treatment subsystem would require the biological growth media to be changed every year at a cost of $500 and various parts for the MBBR or the blowers are estimated at $500 per year. Total O&M costs would be $1,000 per year.

- Incinerator parts are estimated at $500 per year.

A summary of the cost elements is included in Table 4-2.

	Capital Cost	**O & M Cost**
Filtration Units	$150,000 per five years	$131,900 per year
Secondary Unit	$26,000 per five years	$1,000 per year
Incinerator	$11,000 per five years	$500 per year
TOTAL	187,000 per five years	$667,000 per five years
GRAND TOTAL	$854,000 over five years	

Table 4-2. Estimated Capital and O & M Costs

Assuming a continuous operating system for five (5) years and generating 76,000 liters every day for five years, the total liters treated would be 140 million liters.

Therefore, the cost per liter treated is $.006 or about six tenths of a cent per liter.

As stated at the beginning of this section, there are other factors that could impact the cost per liter of waste treated. For example, additional training of operators and maintenance personnel, the cost of additional operator labor, the cost of added fuel consumed to power the system, the cost of added personnel to set up and administer the procurement and life-cycle maintenance of the system, added expense for transportation of the system equipment, etc. However, even using a multiplier of two or three to account for unforseen expenses, the cost per liter of wastewater treated using a geotextile-based filtration system is at least comparable to the present cost for contractor hauling.

SECTION 5

PHASE TWO PLAN

5.1 OBJECTIVE.

The purpose of Phase II is the principal research and development effort that is expected to produce a well-defined deliverable product. This phase is intended to be a demonstration of the technology in a pilot or full-scale unit configured for deployment including the development of operational information on treatment efficiency and hydraulic capacity of the filter, incineration of filter media, odor control, and ash characteristics.

5.2 GOALS.

The goals established are intended to ensure continuity in the research effort and move forward to the ultimate objective of developing a deployable treatment system that will permit discharge of wastewater to local receiving waters. The specific goals are:

- **Continuation of Analysis and Testing.**
  - Phase I testing provided insight into filter performance under static conditions. In Phase II, the hydraulic capacity of the filter as affected by a filter that is moving needs to be determined. A filter moving very quickly will be effective in removing solids but may not make the best use of fabric. Finding an optimum speed where the highest amount of solids are removal for the smallest amount of fabric used is necessary.
  - In Phase II, filter performance as affected by different TSS and BOD strengths and by different average particle sizes will be determined. To date, testing has been performed at municipal wastewater treatment plants where TSS and BOD loading and where the average solid particle size have been low compared to what might be expected in an actual Force Provider module. Testing an actual Force Provider wastestream will verify WFU performance at high TSS and BOD loadings and may provide insight into the effects of particle size.
  - There are other media that could offer great promise for filtration. For example, paper products may exhibit the same or better capacity for passing water but have a greater ability to retain particles because of smaller interstitial spacing. In research to date, geotextile materials have been used with an apparent opening size in the range of 100 microns. There are filters, typically used in ventilation air systems, that are extremely efficient at removing particles in the 10 micron range – High Efficiency Particulate Air or HEPA filters. These are thicker than the filter media tested so far but they are also reusable. These and other filtration media may offer great improvements in WFU performance and costs.

- The mechanical handling characteristics of the filter media can have a significant impact on the design of the filtration subsystem. For example, the low tensile strength of geotextile materials required reinforcing the edges of the fabric sheets so they could be pulled through the filter without deformation and related changes in properties. Geotextile fabric is very brittle in temperatures below freezing. More needs to be known about how various types of filter media can be configured so that physical weaknesses are minimized and optimum configurations for mechanical handling are developed.

- The filtration subsystem by itself will not satisfactorily meet treatment requirements. A compatible secondary treatment subsystem that can be adapted to the WFU to form a complete system needs to be identified. Testing will be essential to ensure that the secondary technology that is selected meets the constraints required for use in the Force Provider or similar wastewater treatment application.

- Combustion of the sludge generated in the WFU appears to be the most appropriate technology for ultimate disposal of the filtrate. There is much more to be learned about the combustion characteristics of the filter media. Much of this information will need to be generated by empirical methods that mimic the WFU application. The data developed in the research may be used to refine the incinerator configuration. Finally, the incinerator exhaust may need to be altered to include exhaust treatment components to ensure the discharge is environmentally acceptable.

- After more is discovered about the performance and mechanical handling characteristics of various filter media, the information will need to be factored into the analysis and testing to find the best configuration for the filtration tub. For example, the optimum size and shape of the filter aperture will require study and application of data from filter media performance testing.

- **Design an Integrated System.**

With a solid foundation of information about component and subsystem characteristics and performance, design of the total system can be completed. The goal will be to select the appropriate mix of commercially-available, off-the-shelf items that can be combined with build-from-scratch components to form a fully functional system. For example, experience to date indicates that the filtration tub will have to be designed and built but the secondary and incinerator subsystems can be purchased and modified for our application.

It may also prove beneficial to install an additional WFU in the blackwater stream prior to the bladder. This may enhance removal of additional particles.

- **Build and Test a Full-Scale Prototype.**

The central goal in Phase II will be the assembly of components and construction of the prototype. Construction will have to be performed with testing goals in mind so that the construction or final assembly site is conducive to the tests that have to be performed. Instrumentation will need to be installed as part of the construction process and the construction/test site will need to have a source of liquid waste that replicates as closely as possible the actual conditions under which the unit will be expected to operate. Appropriate operating permits will need to be identified and obtained. A rigorous and well-defined test plan must be created to ensure the unit is operated under normal and extreme circumstances to identify any shortcomings.

- **Evaluate the Prototype.**

The data generated in testing must be reduced in order to develop conclusions and recommendations about performance. In addition to the technical aspects related to performance, the components will need to be examined for durability, maintenance requirements, life-cycle costs, ease of deployment and setup/strikedown, operation in extreme weather, and operator training requirements.

5.3 THE PLAN.

If asked to submit a proposal for Phase II, UTD would use the following five tasks as a starting point to plan to accomplish the goals listed above.

5.3.1 Analysis and Testing.

The aim of this task is to build upon and expand the knowledge of various filter media including characteristics under both static and dynamic conditions. A data set that describes the characteristics of the incineration process for all potential filter materials has to be developed. The best method of handling the filter media from storage through filtration and incineration must be developed. The suitability of the various secondary treatment methods that can be incorporated into the WFU concept would be identified and evaluated.

5.3.2 Design and Integration.

The components needed to form a complete system would be selected and the inter-connections needed to form a functional system identified. The performance parameters, drawings and specifications for each component and for the system as a whole would be developed. Operating and installation manuals for the WFU and integrated waste process system would be generated.

5.3.3 Construction.

All of the components to form the full-scale prototype would be purchased, fabricated, and/or assembled.

5.3.4 Commercialization.

A business plan that identifies the nature and size of the market, the marketing strategy and approach, and the sale and distribution of products would be developed.

5.3.5 Final Report.

Document all of the analytical, testing, integration, development, and commercialization efforts.

5.4 SCHEDULE.

The Phase II schedule for task sequencing and completion would look like Figure 5-1. Actual dates would depend upon contract and subcontract execution dates.

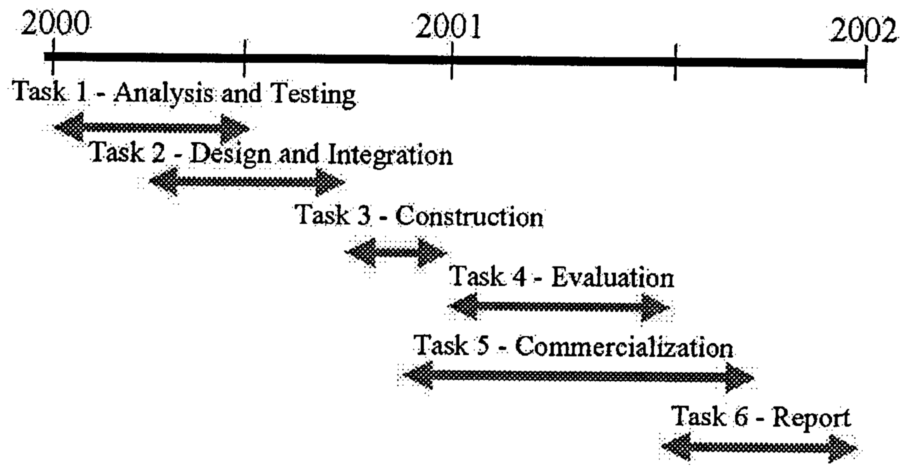

Figure 5-1. Generic Schedule for Phase II.

5.5 PROJECT TEAM.

Since the STTR program requires a team with a small business and an academic or research institute, the UTD plan incorporates at least one academic partner. While the Catholic University of America (CUA) provided assistance for Phase I additional partners will be assessed for Phase II. Dr. Led Klosky, who had oversight for filtration research in Phase I, left CUA in December 1999 and accepted a position on the faculty of the United States Military Academy at West Point. The use of Dr. Klosky's expertise for Phase II will be contracted directly or through West Point.

CUA will continue to be a team member in order to gain the combustion/incineration expertise in the form of the Chairman of the Mechanical Engineering Department, Dr. Sen Neih. Finally, University of Maryland has been contacted to determine the availability of Dr. Oliver Hao who has worked with secondary treatment systems in wastewater plants for many years.

5.6 COST.

It is understood that funding for Phase II, depending on the scope of work desired, would be approximately $500,000 as stated in the STTR announcement.

APPENDIX A

Geosynthetic Material Data

Table A-1 lists some properties of a sampling of geosynthetic fabrics.

Company and Product Name	**Opening Size (mm)**	**Unit Weight (g/m^2)**	**Thickness(mm)**	**Manufacturing Method**
Amoco 4504	.212	135	.85	Needle-punched
Amoco 4510	.15	339	2.15	Needle-punched
Amoco 4516	.15	542	2.90	Needle-punched
LINQ 3401	.212	135	.40	Spunbonded
LINQ 3501	.220	169	.50	Spunbonded
LINQ 3601	.106	203	.48	Spunbonded
LINQ 3801	.075	271	.50	Spunbonded
Mirafi 1100N	.150	339	2.5	Needle-punched
Mirafi 1120N	.150	387	3.0	Needle-punched
Mirafi 1160N	.150	492	3.8	Needle-punched
Synthetic Industries 1001	.150	---	---	Needle-punched
Synthetic Industries 1701	.150	540	---	Needle-punched
Texel 7605	.08-.120	---	.9	Needle-punched, heatset
Texel 425 PE 200 S	.135 ± 20	425 ± 30	3.2 ± .4	Needle-punched, singed
Webtec N03	.210	152	No published values	Needle-punched
Webtec N08	.18	---	No published values	Needle-punched
Webtec N10	.15	---	No published values	Needle-punched

Table A-1. Geotextile Fabric Properties.

The points of contact that we developed in the course of researching geosynthetic fabrics are listed in Table A-2.

Company	Contact	Phone/E-mail Address	Mailing address
Amoco	Winfred Brown	(800) 445 7732 brownwb@bp.com	
LINQ	Warren Johnson	(800) 543 9966 johnsonw@linqind.com	
Mirafi	Tom Rew (Regional Rep),	(410) 821 8658	1421 Providence Rd. Suite 100 Towson, MD 21286
	Janice Hall (for technical data)	(800) 550 4510	
Synthetic Industries	Nina Miller	(800) 621 0444 xt. 32631 nena_miller@sind.com	
Texel	Valerie Despaux	(418) 387 5910 valerie.despaux@texel.qc.ca	
	John Lewis	(252) 492 6018	1548 Peter Gill Rd. Henderson, NC 27536
	Jeff Gentry (Regional Rep)	(513) 336 0183	
Webtec	Keith Harris	(800) 438 0027 info@webtecgeos.com	P.O. Box 240302 Charlotte, NC 28224-0302

Table A-2. Geosynthetic Manufacturer Points of Contact.

APPENDIX B

Experiment Raw Data

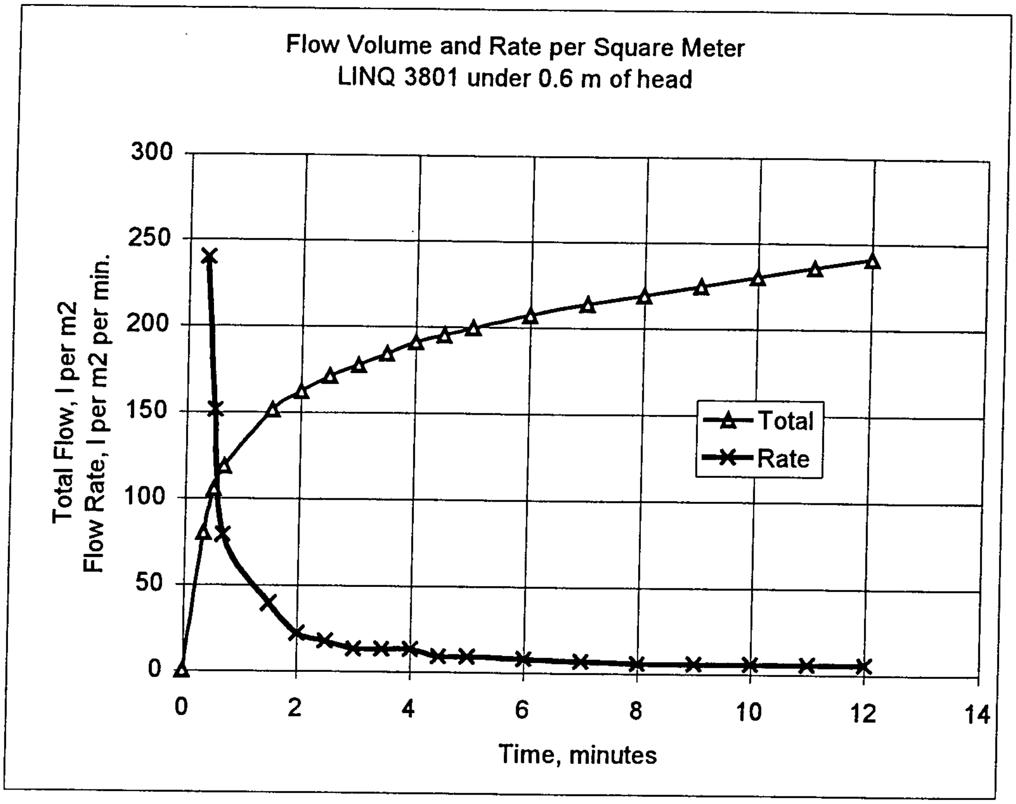

Figure B-1. Data from Test L-3F on October 29, 1999.

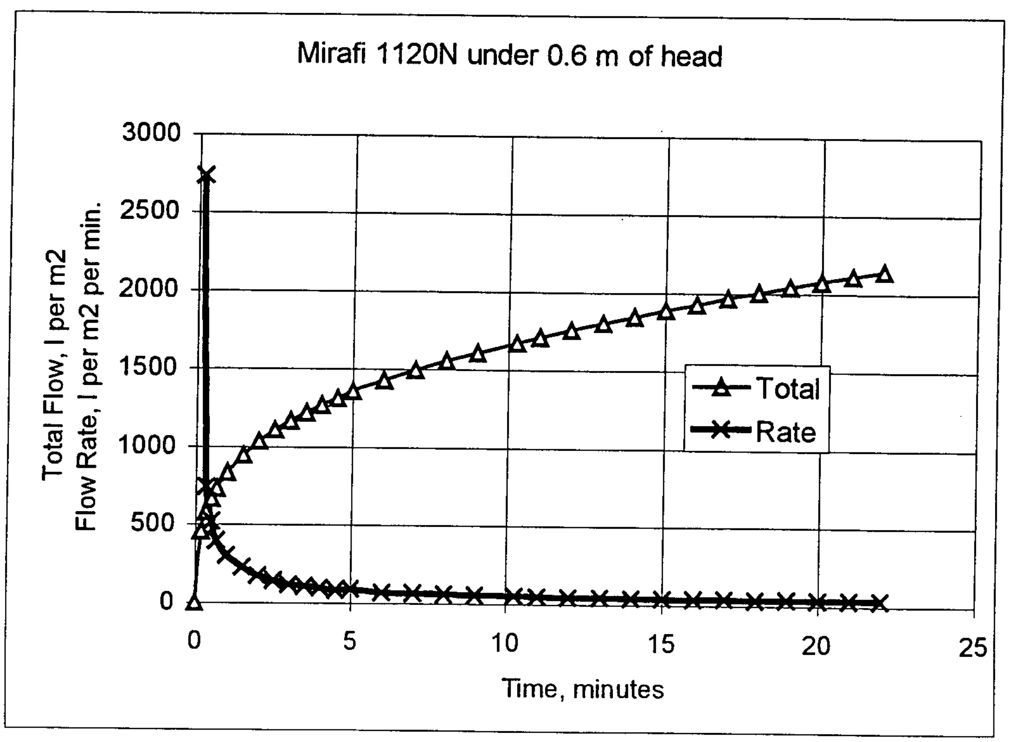

Figure B-2. Data from Test M-1F on November 3, 1999.

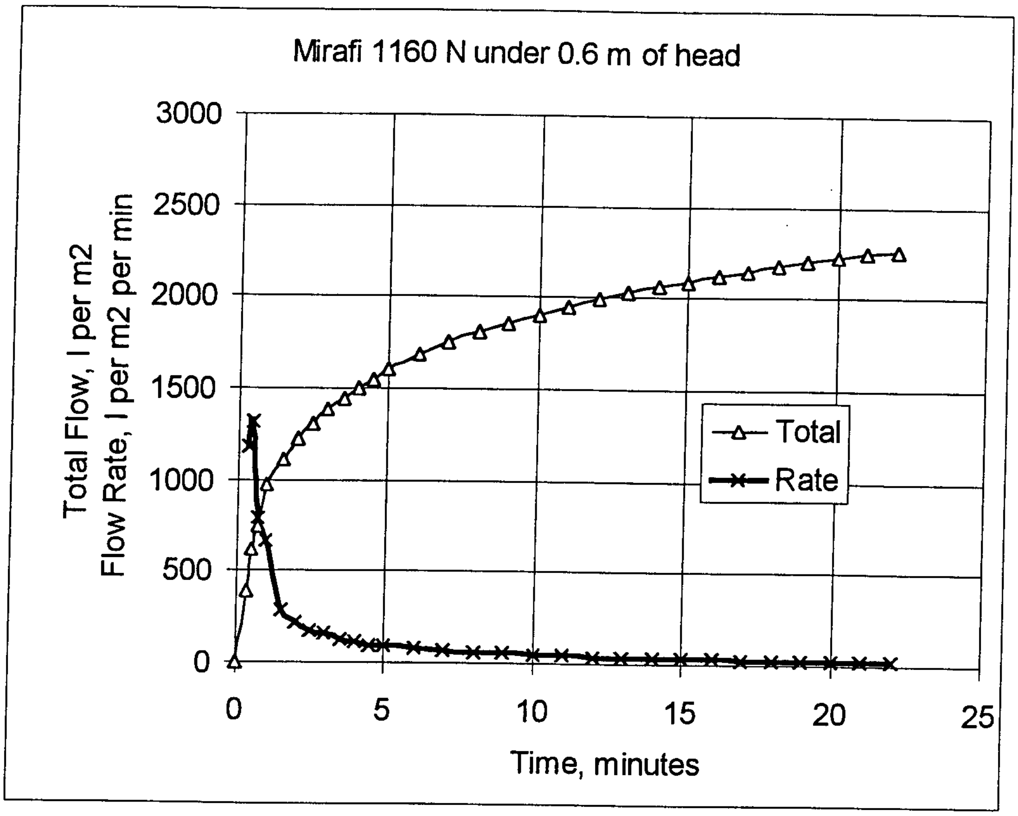

Figure B-3. Data from Test M-2F on November 3, 1999.

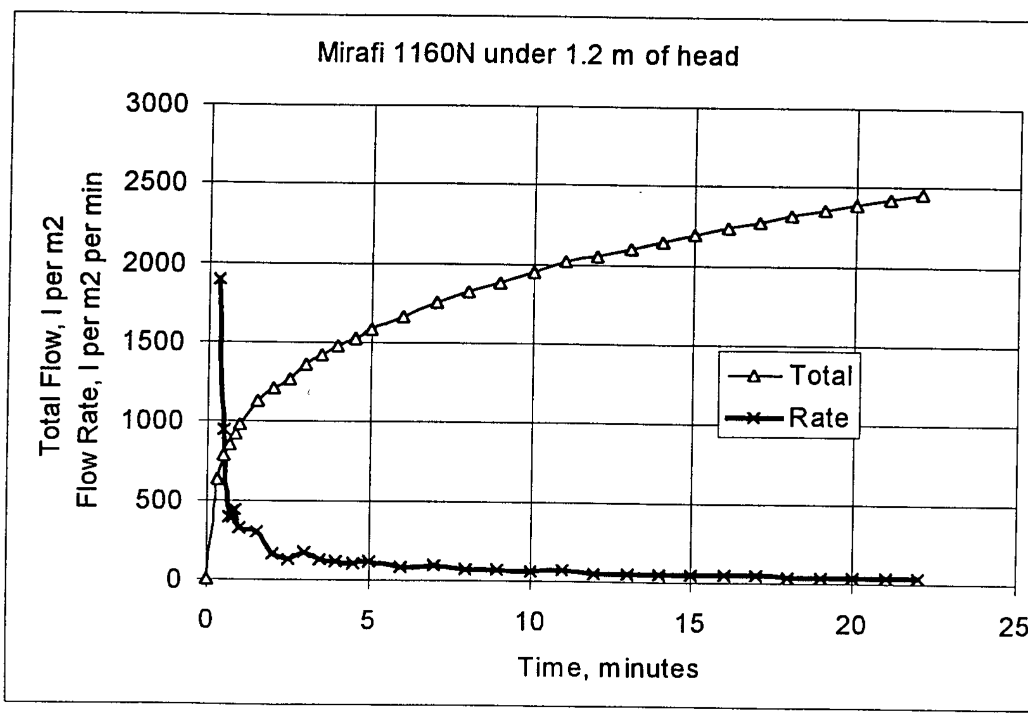

Figure B-4. Data from Test M-3F on November 3, 1999.

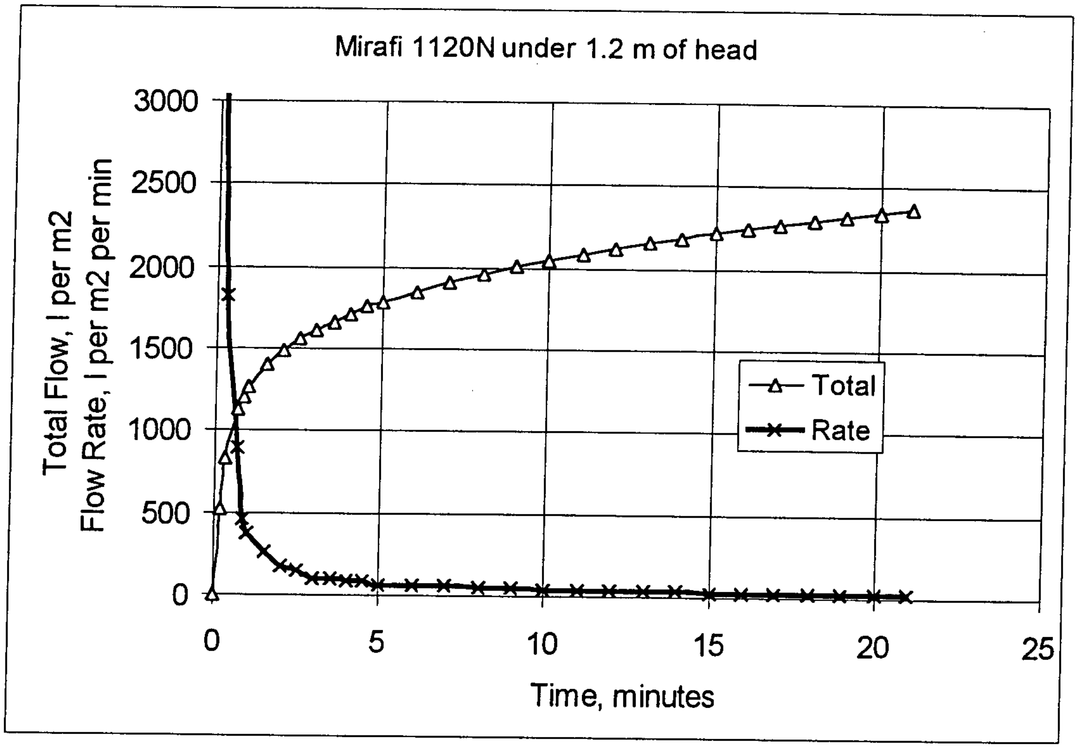

Figure B-5. Data from Test M-4F on November 3, 1999.

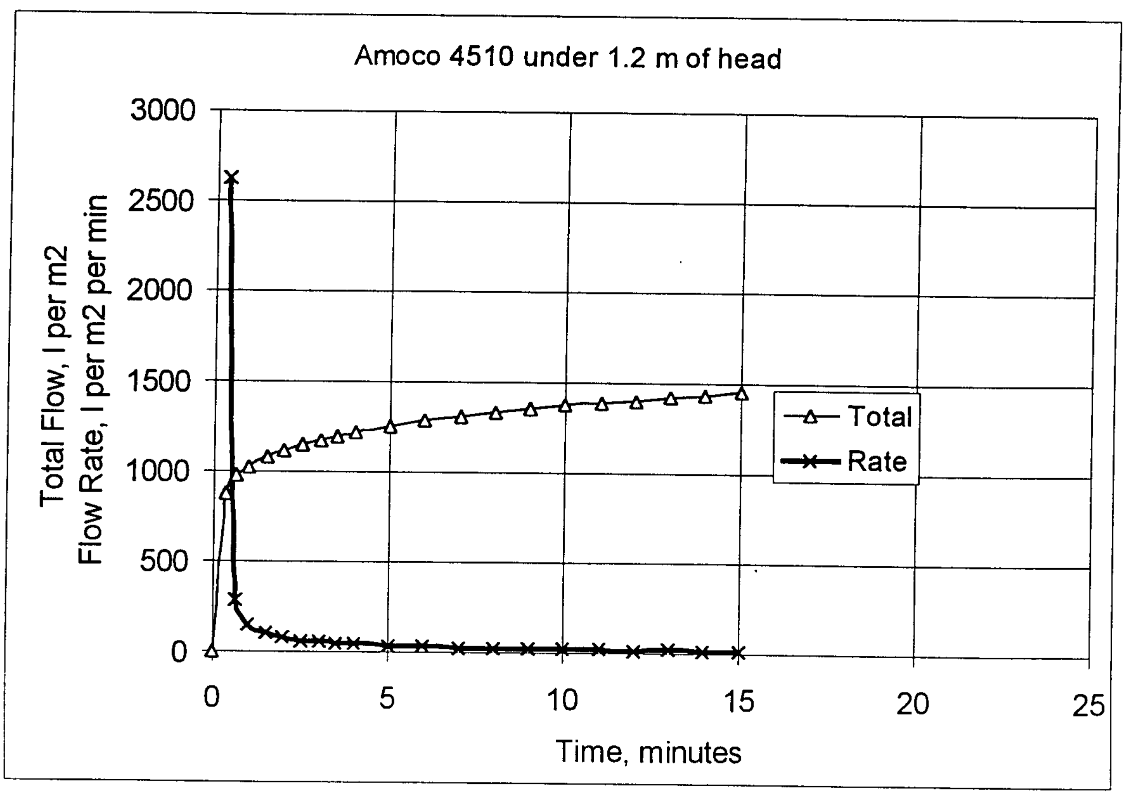

Figure B-6. Data from Test A-4F on November 5, 1999.

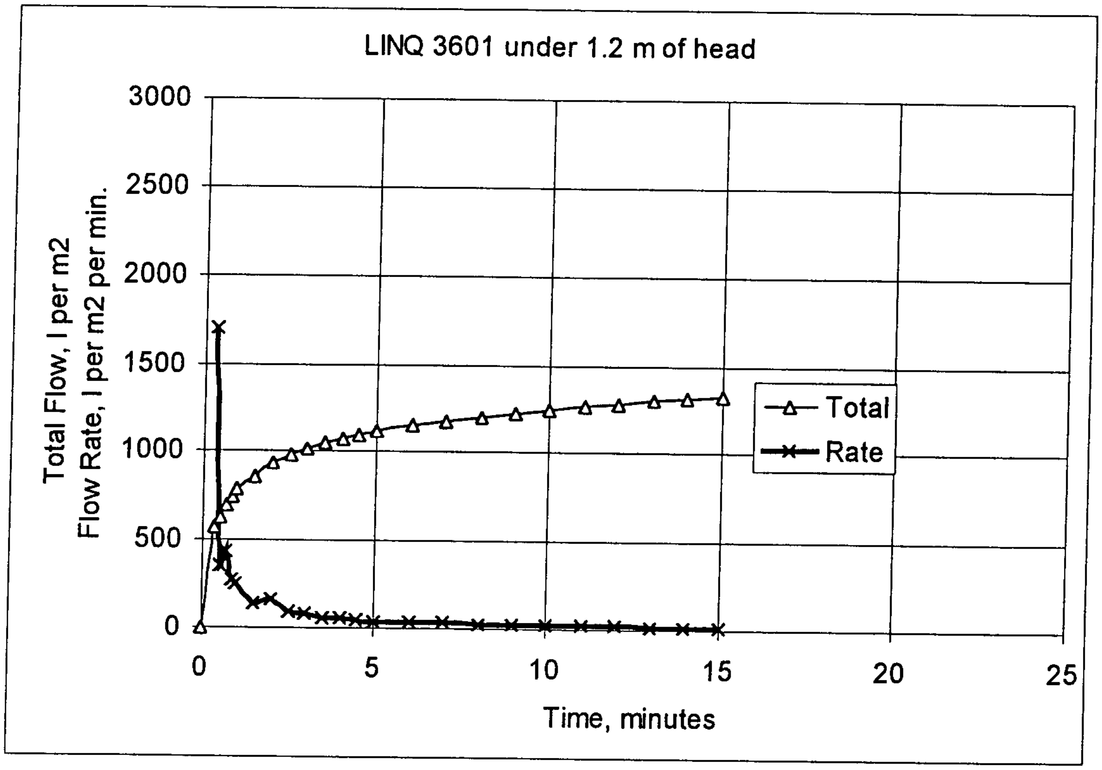

Figure B-7. Data from Test L-5F on November 5, 1999.

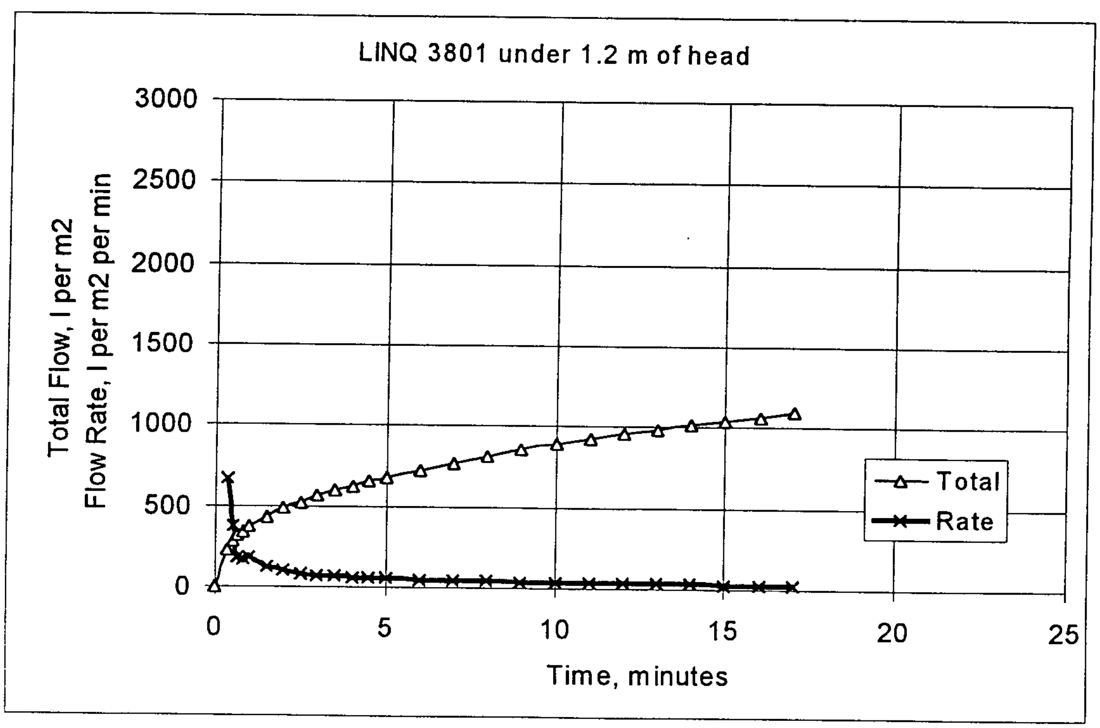

Figure B-8. Data from Test L-6F on November 5, 1999.

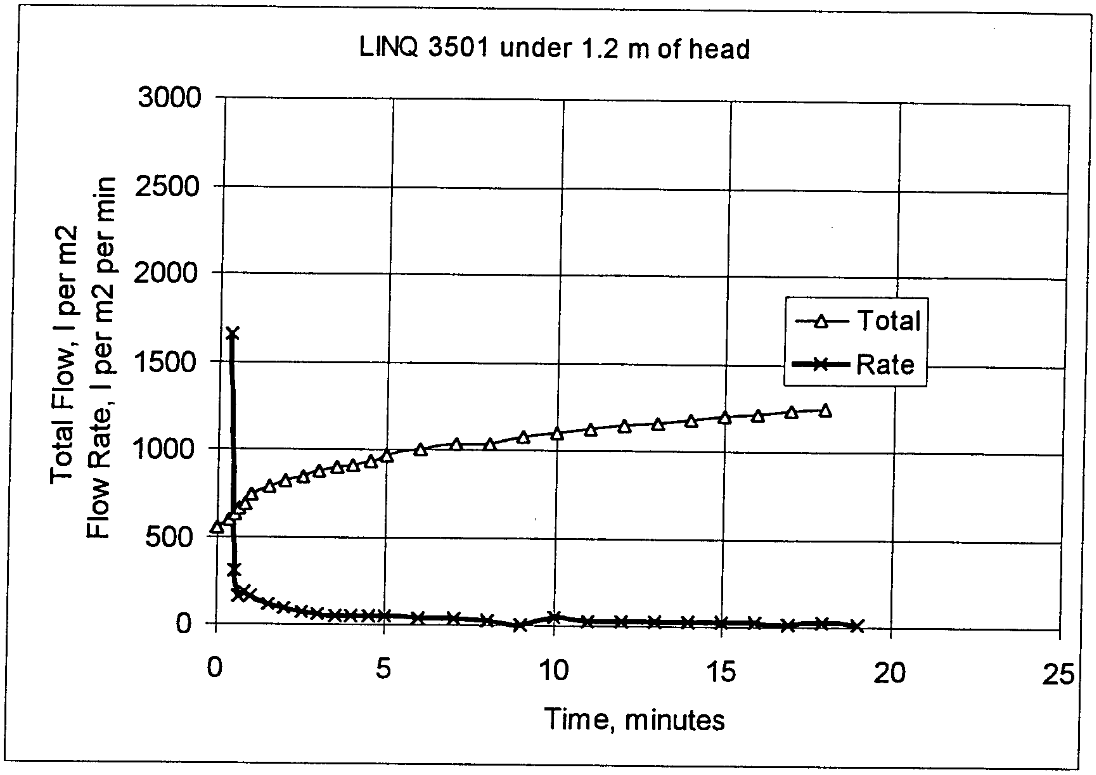

Figure B-9. Data from Test L-7F on November 5, 1999.

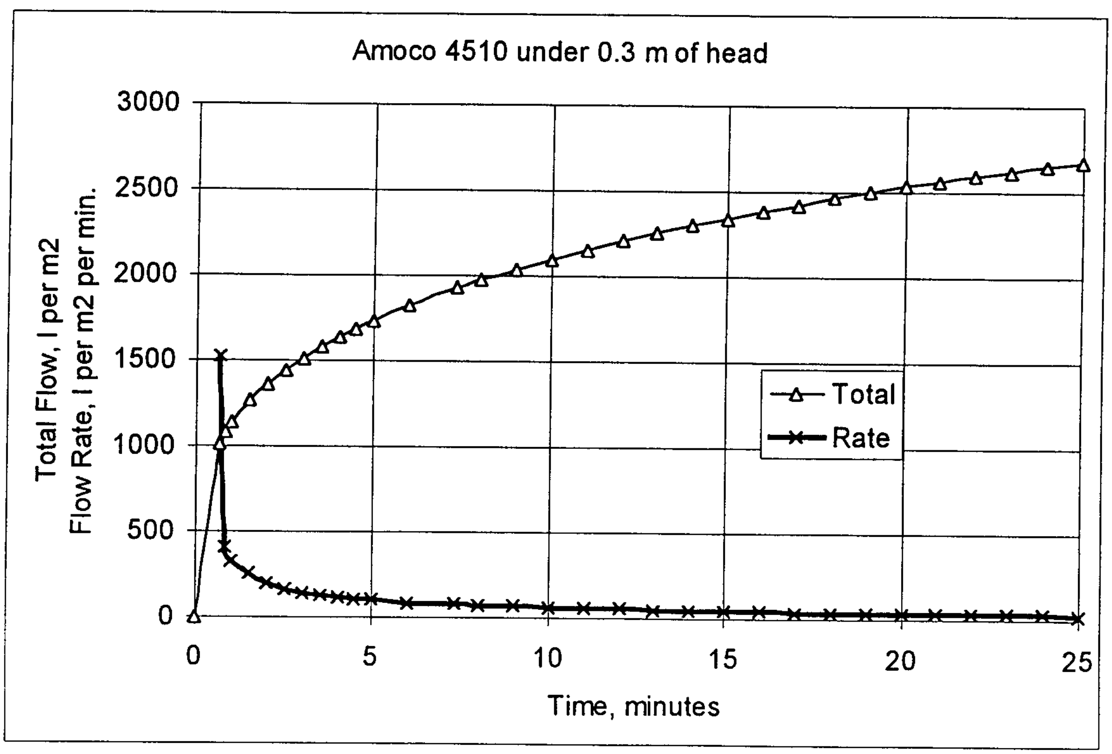

Figure B-10. Data from Test A-5F on November 12, 1999.

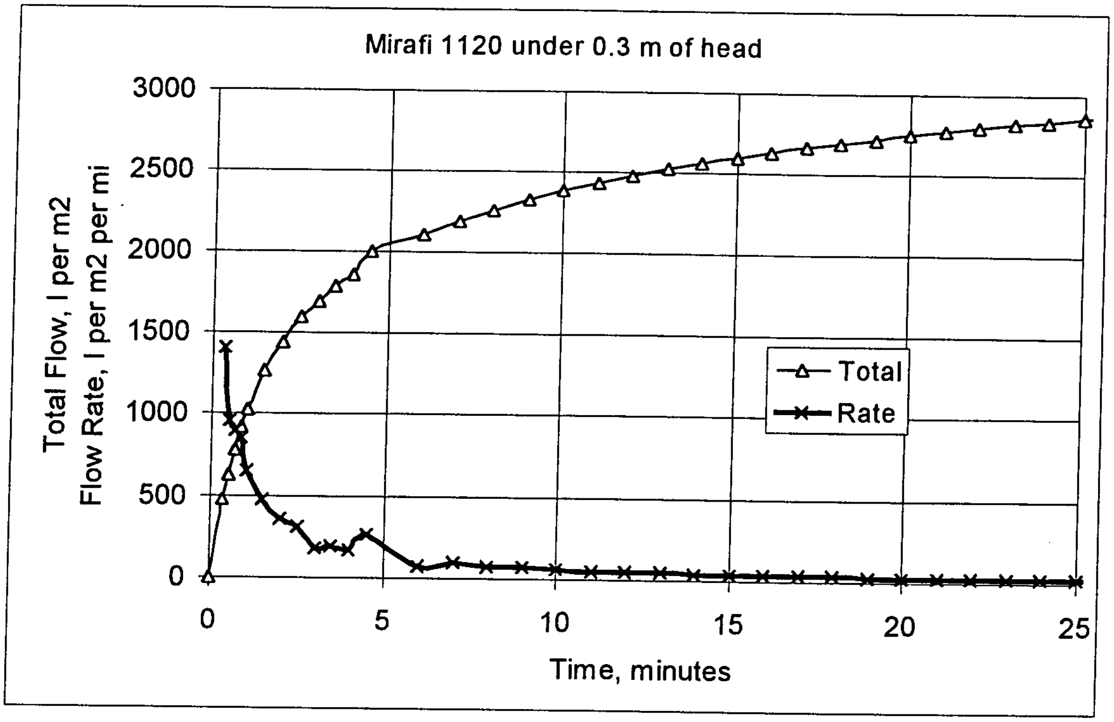

Figure B-11. Data from Test M-5F on November 12, 1999.

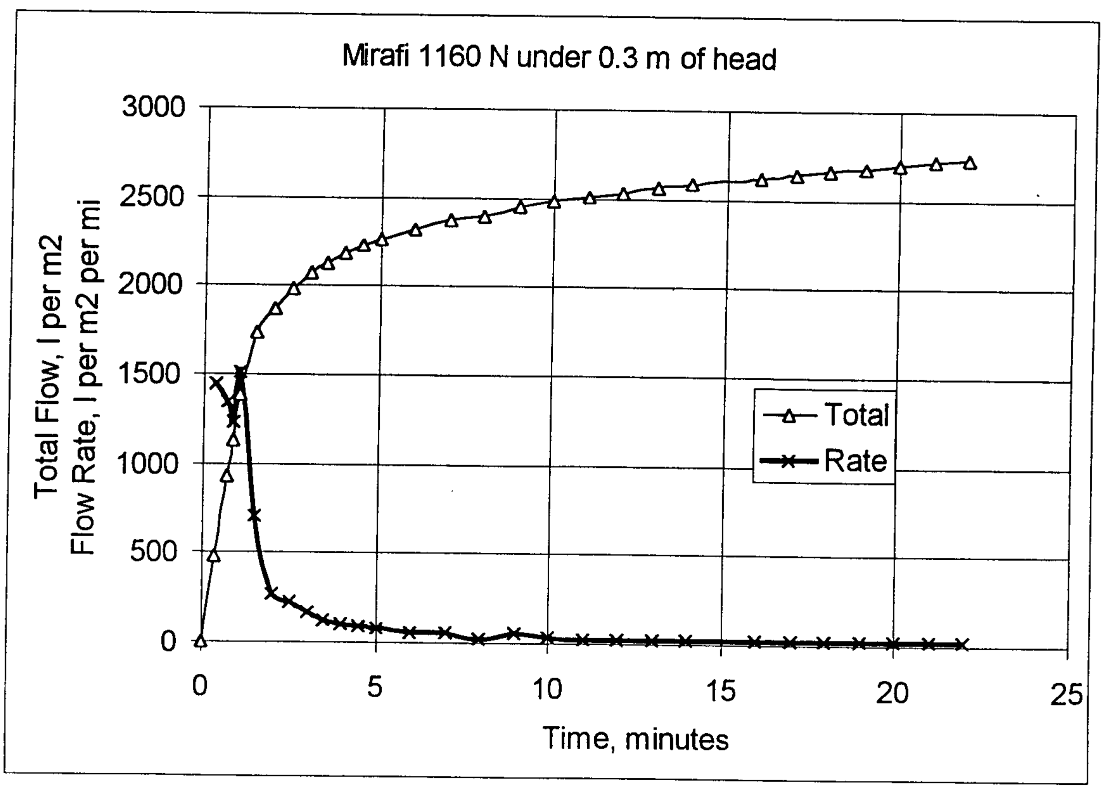

Figure B-12. Data from Test M-6F on November 12, 1999.

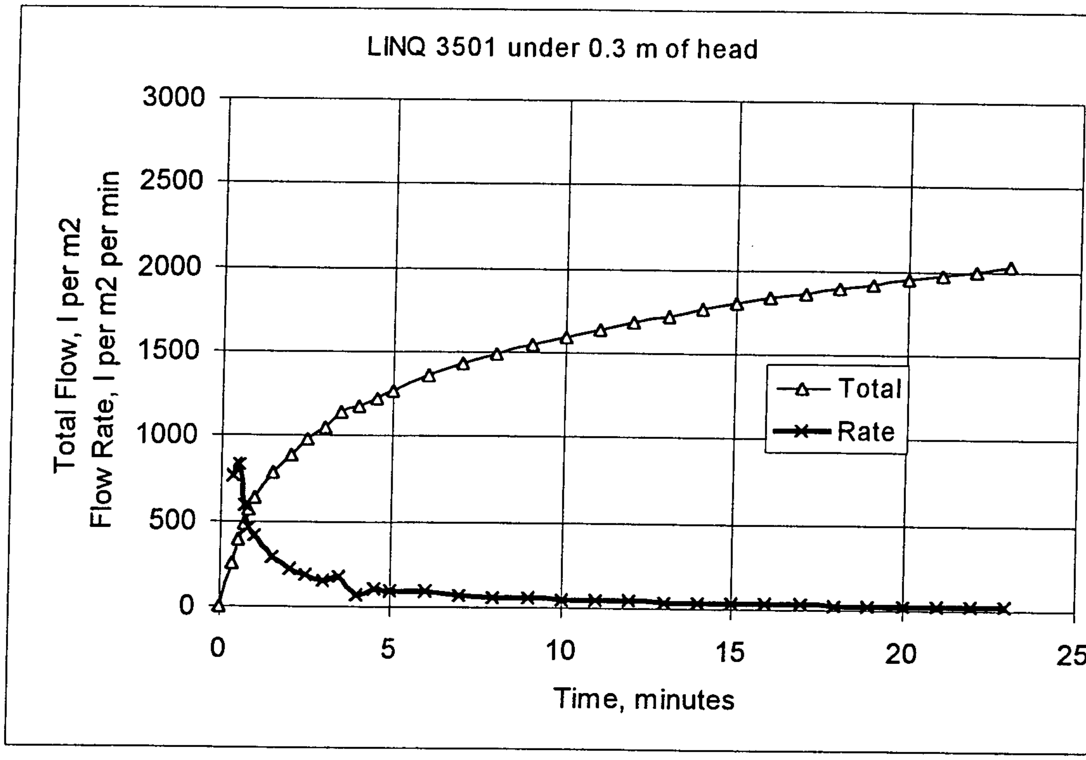

Figure B-13. Data from Test L-8F on November 12, 1999.

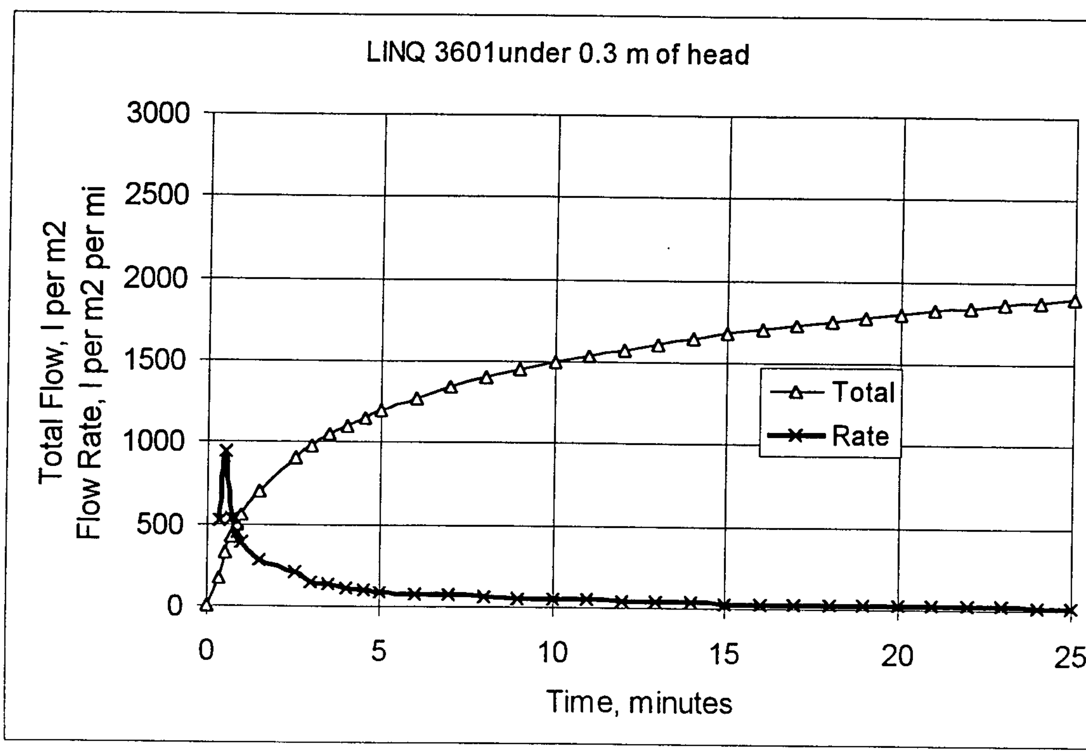

Figure B-14. Data from Test L-9F on November 12, 1999.

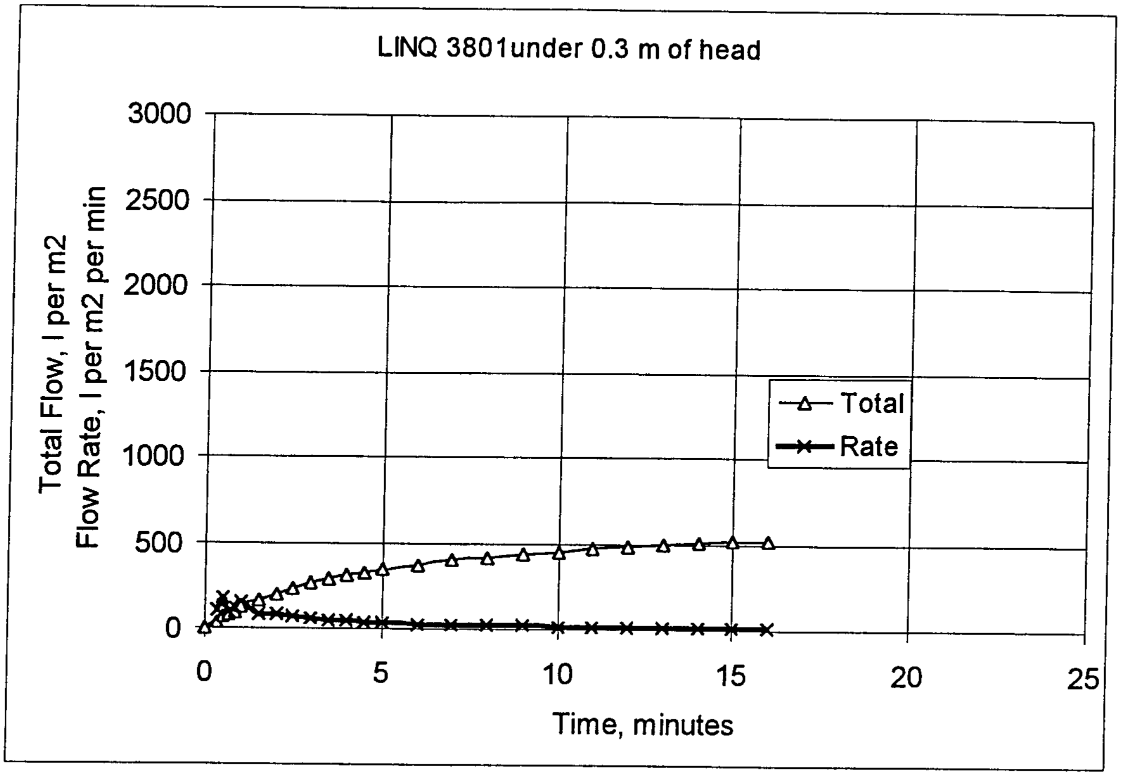

Figure B-15. Data from Test L-10F on November 12, 1999.

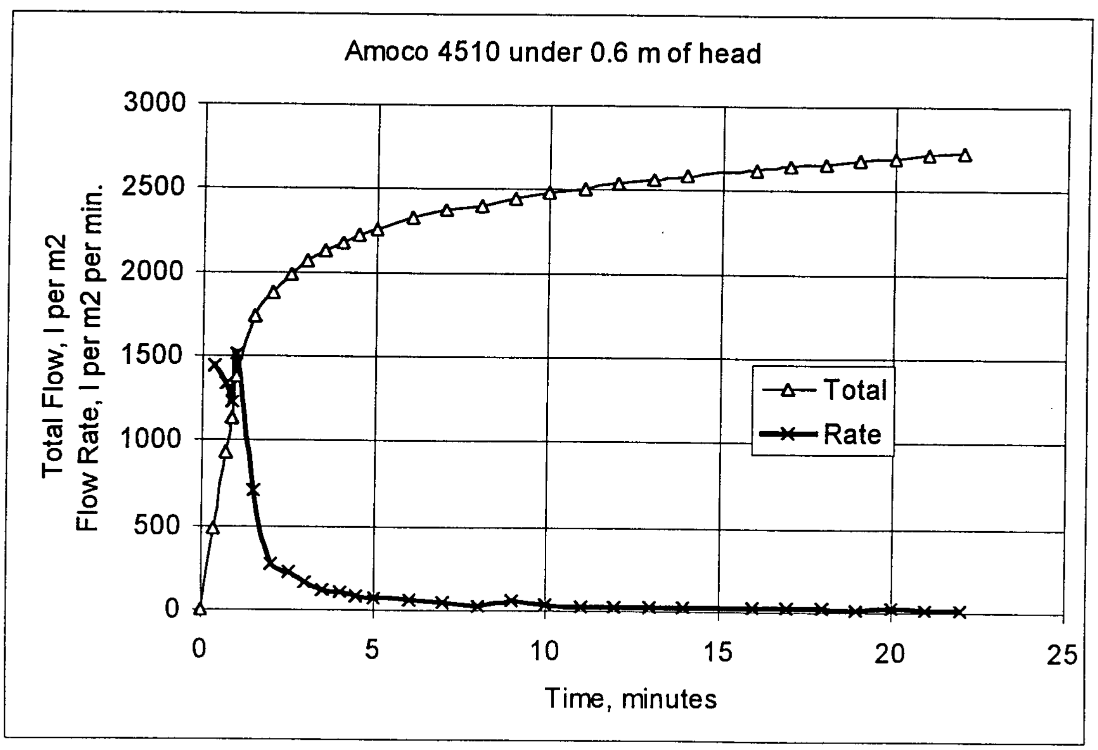

Figure B-16. Data from Test A-6F on December 1, 1999.

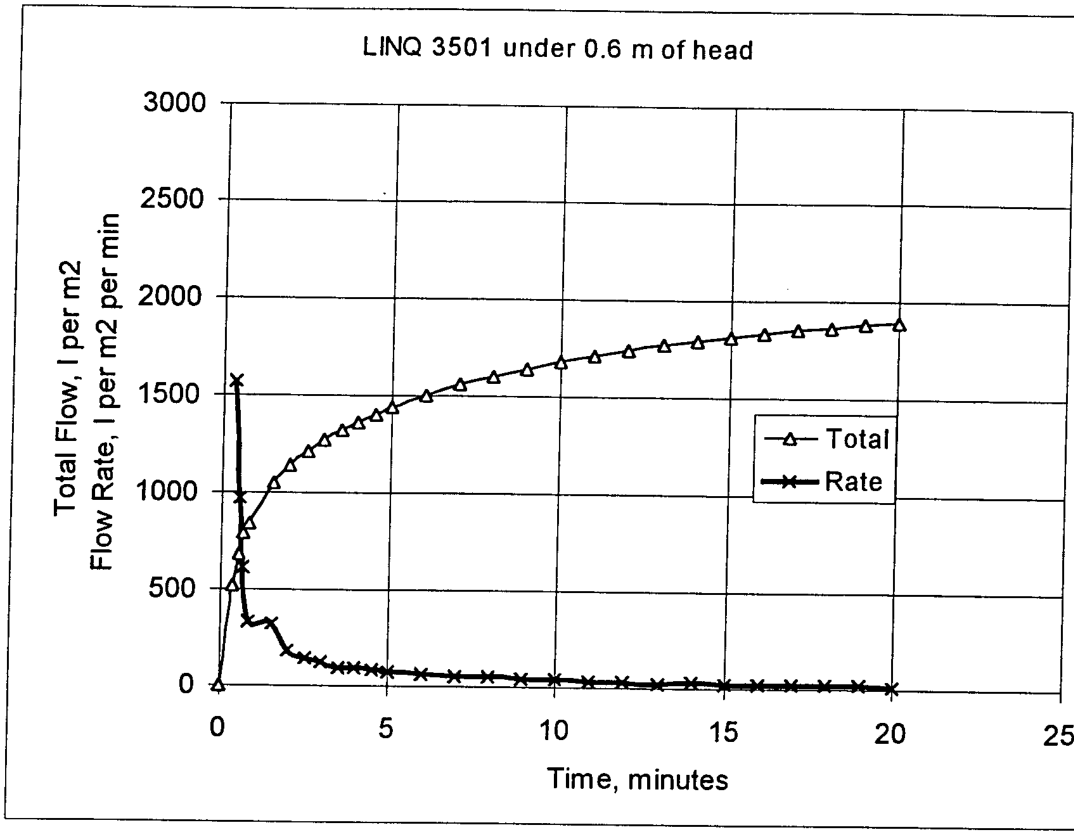

Figure B-17. Data from Test L-11F on December 1, 1999.

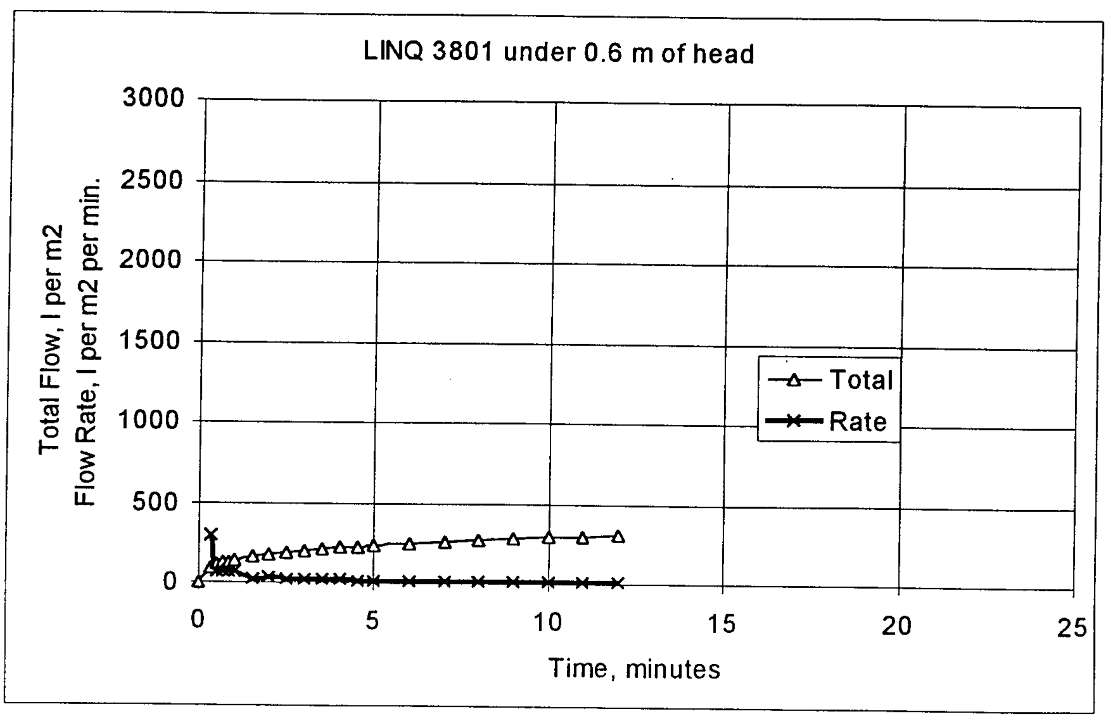

Figure B-18. Data from Test L-12F on December 1, 1999.

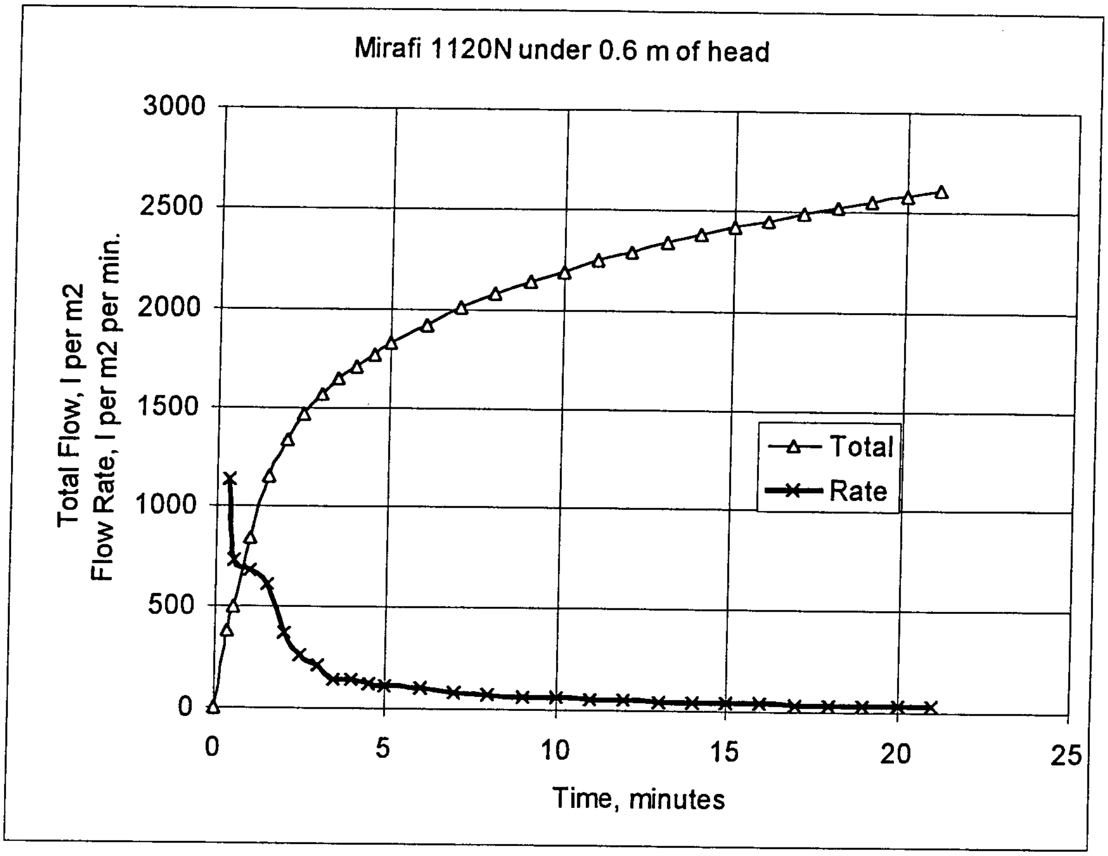

Figure B-19. Data from Test M-7F on December 1, 1999.

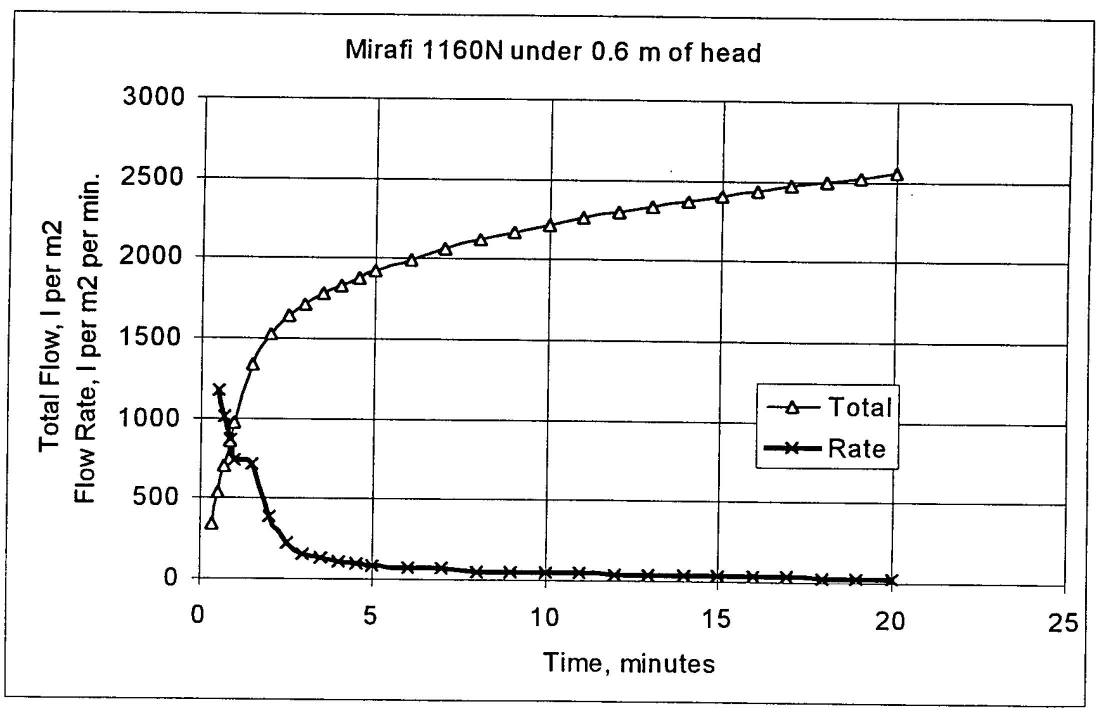

Figure B-20. Data from Test M-8F on December 1, 1999.

APPENDIX C

Mechanical Handling Analysis Data

There were a number of different shapes and configurations studied for the filtration tub. The central issues to resolve were:

- How to keep the wastewater from leaking past the filter fabric.
- How to avoid moving parts in areas where sludge might collect.
- How to make it easy to change the filter fabric.
- How to minimize the operator attention and electrical power required to operate the filter device.

Using the relationships discussed in Section 3-3, we analyzed the following configurations.

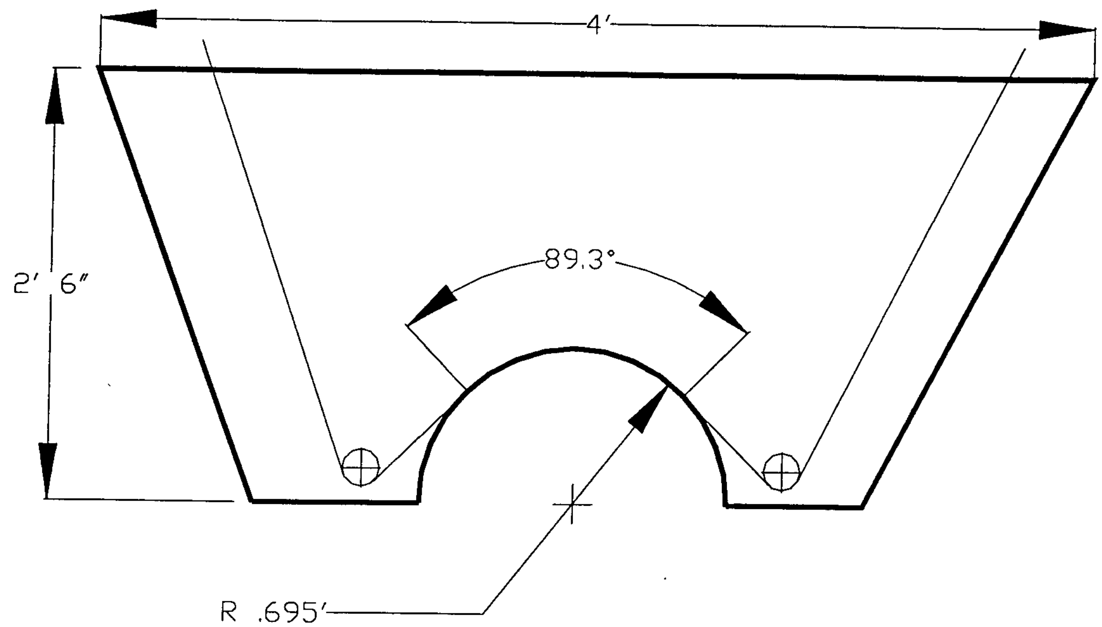

Figure C-1. Early Tub Configuration.

Analysis of a thin fabric with low tensile strength showed the need for a small diameter arc over which the fabric would move. Therefore, the contact angle would have to be large. This meant using use two rollers at low points in the tub where sludge will collect. In addition to the added maintenance required for two rollers that would constantly be under a layer of sludge, it was concerned about the "squeegee effect" would exit the second roller. The second roller would squeeze waste out of the fabric rather than keep it entrained.

Analysis of a thicker fabric with greater tensile strength, indicated a larger diameter arc and smaller contact angle was possible. This is depicted in Figure C-2.

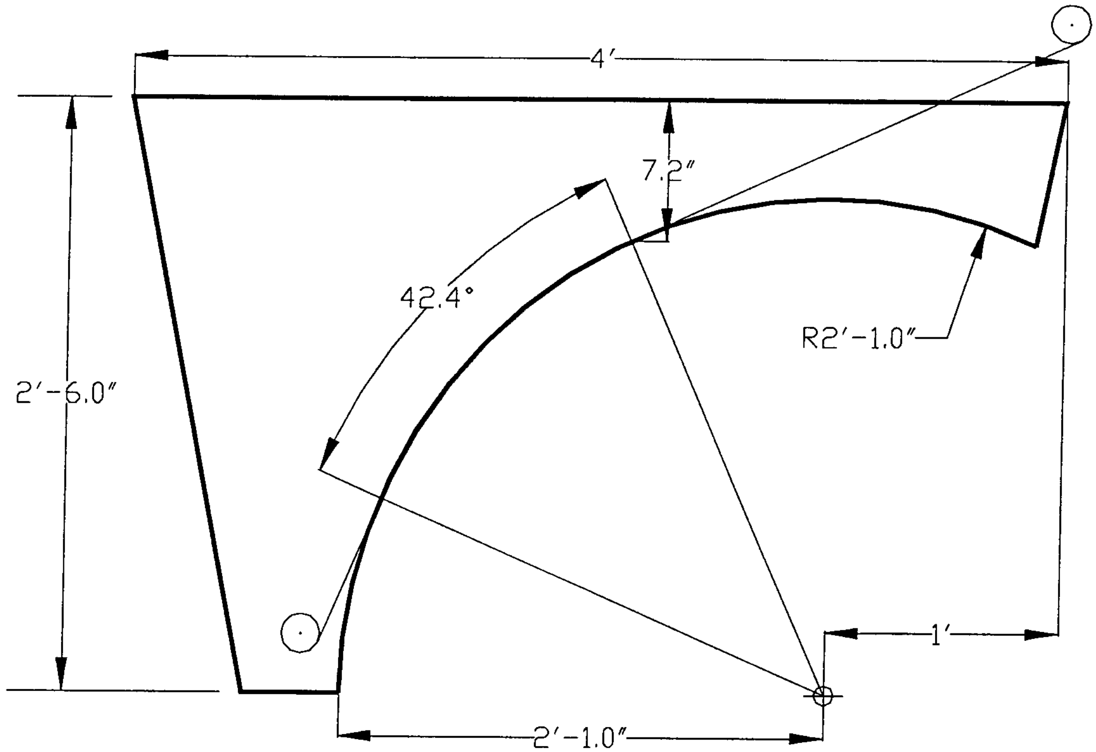

Figure C-2. Early Tub Configuration.

In the configuration in Figure C-2 there still was a roller in the sludge and the tub volume was reduced to accommodate the large arc.

The next configuration examined is shown in Figure C-3. In this variation, the wastewater flows upward through the fabric and perforated arc and into the semi-circular effluent basin. This configuration eliminated the need for rollers that could get caught in the sludge. It also provided a system where it would be easy to change the fabric since there would be no need to reeve the fabric through rollers. Also, the ability of the wastewater to flow vertically upward was a concern as well as the entrained waste falling off the fabric as the fabric moved from the perforated surface to the take up roller. This configuration would also require an effluent pipe joint that would have to be continually opened and closed and could, as a result, turn into a maintenance problem.

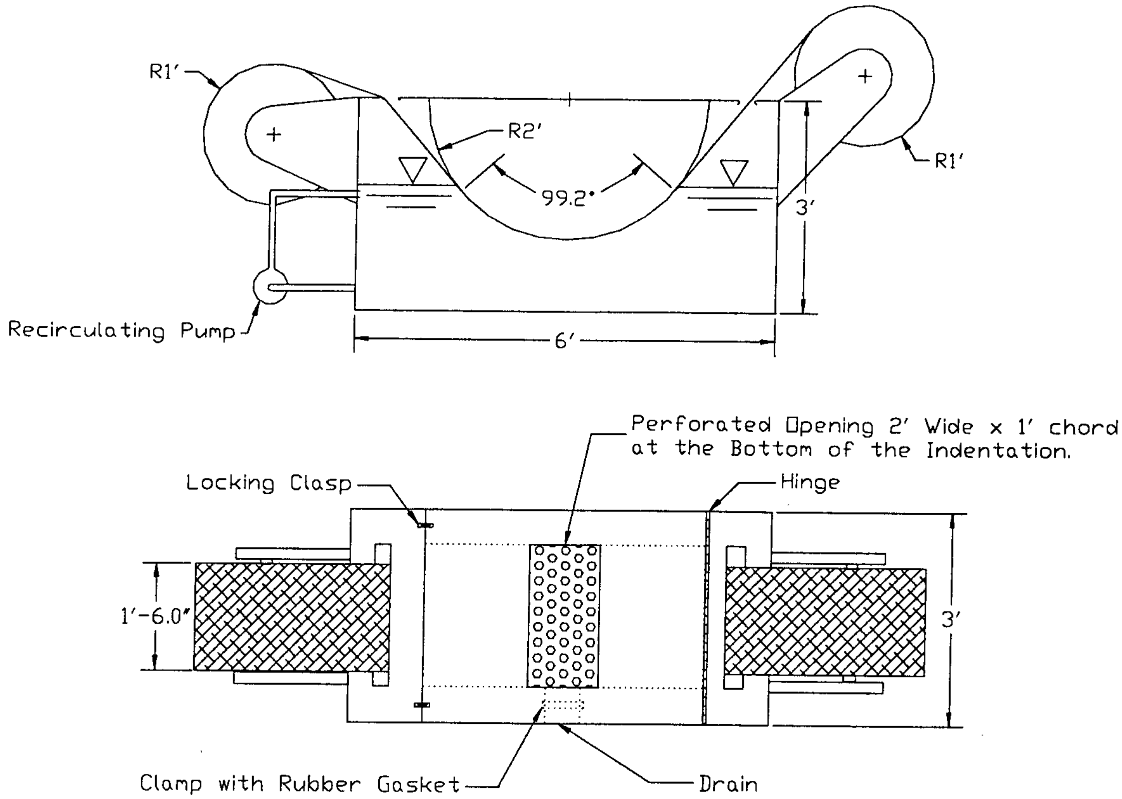

Figure C-3. Tub Configuration with Flow Upward through Fabric and Perforated Surface.

The next step was to examine the configuration shown in Figure C-4. The idea here was to flow wastewater downward through the semi-circular tub through the perforations and then through the fabric which would move across the underside of the tub. This setup would avoid rollers in the sludge, make it easy to change fabric rolls, and provide a good downward flow. However, it was thought the fabric might have a tendency to be pushed away from the tub perforations by the downward flow of wastewater and create hydraulic short circuits. There was also some concern about sludge building up on top of the perforated surface.

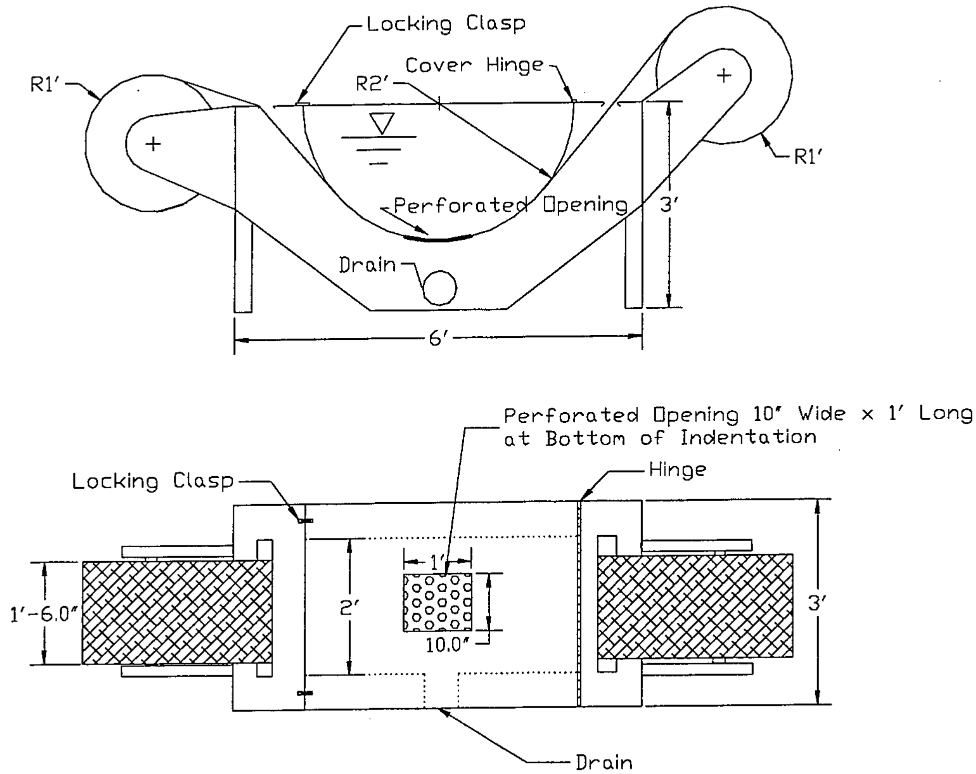

Figure C-4. Configuration with Vertical Downward Flow and Fabric under the Perforations.

The final configuration we studied is shown in Figure C-5. The concept in Figure C-4 was altered by placing the fabric inside the tub. To do this, the channel guides were placed on each side of the tub to keep the fabric in position since it is slightly buoyant. Nylon straps needed to be sewn into the edges of the fabric strips to provide the required tensile strength.

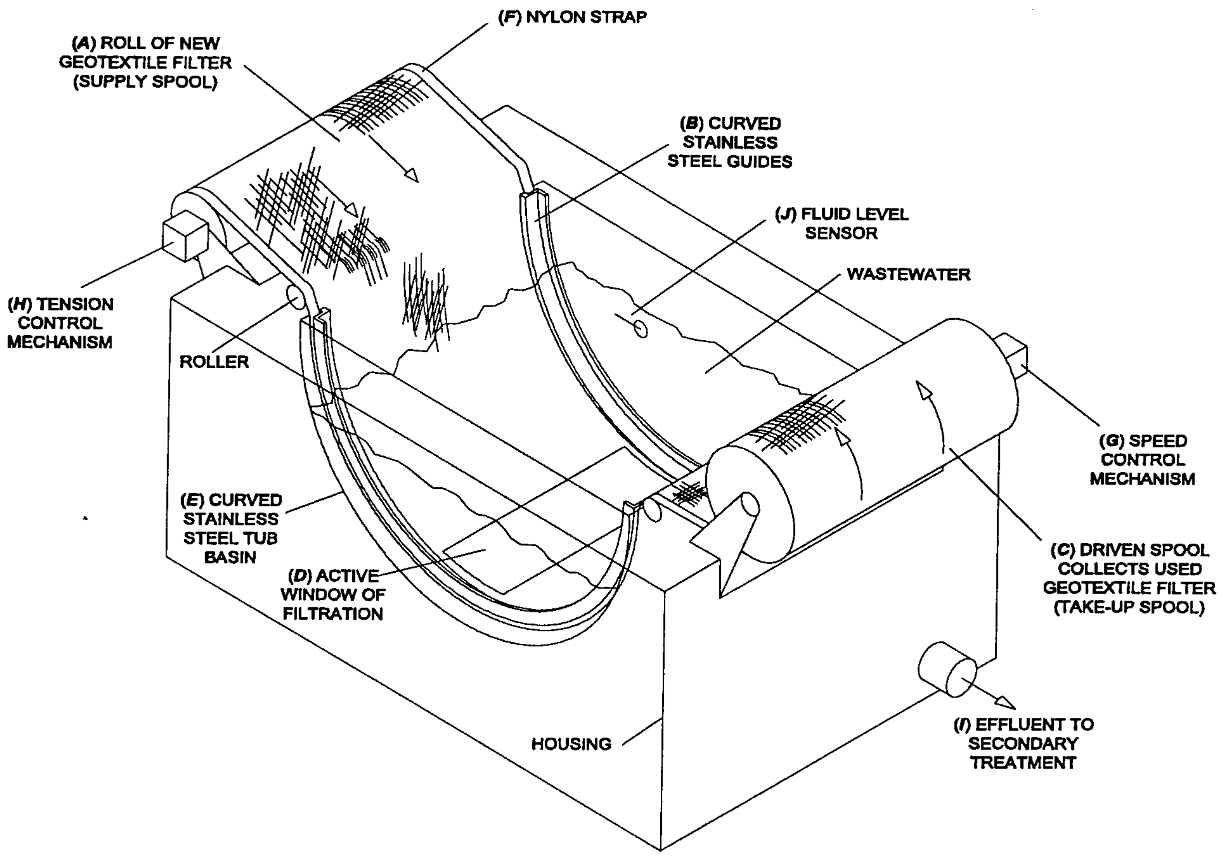

Figure C-5. Filter Fabric Runs under Guides Inside the Tub.

Appendix Table C-1